



## Original research

# Electrocardiographic findings in elite professional cyclists: The 2017 international recommendations in practice



Anna L. Beale<sup>a,b,\*</sup>, Mallaury V. Julliard<sup>a</sup>, Philippe Maziarski<sup>a</sup>, Jean-Luc Ziltener<sup>c</sup>, Haran Burri<sup>a</sup>, Philippe Meyer<sup>a</sup>

<sup>a</sup> Cardiology Service, Geneva University Hospitals, Switzerland

<sup>b</sup> Monash University Central Clinical School, Australia

<sup>c</sup> Centre for Sports Medicine and Exercise, Clinique la Colline, Switzerland

## ARTICLE INFO

## Article history:

Received 3 December 2017

Received in revised form 25 May 2018

Accepted 28 June 2018

Available online 5 July 2018

## Keywords:

Athlete

Electrocardiography

Cyclist

Screening

Men

Guidelines

## ABSTRACT

**Objectives:** To categorize ECG findings into normal, borderline or abnormal in a team of professional elite cyclists according to the 2017 international recommendations.

**Design:** A cross-sectional study was performed.

**Methods:** Twelve-lead ECGs collected between 2012 and 2015 as part of an annual routine examination for a team of professional elite cyclists were analysed, and findings classified as normal, borderline or abnormal according to the 2017 recommendations. Information on exercise capacity testing was also collected.

**Results:** A total of 43 professional cyclists, all Caucasian males ranging between 21 and 38 years of age, were included. Given most were followed up for multiple years, a total of 103 ECGs were collected. Normal variations were found in 43 (100%) athletes; borderline findings in 4 (9.3%), and 2 (4.7%) athletes had abnormal findings. No pathology was identified on further investigation of the four cyclists with two concurrent borderline or any abnormal ECG findings, reflecting a false positive rate of 9.3%.

**Conclusions:** In this team of professional cyclists, the prevalence of abnormal ECG findings requiring further investigation, and the false positive rate were low, despite a very high prevalence of normal variations expected in athletes. This may be as a result of heightened specificity of the new international recommendations for ECG interpretation in athletes.

© 2018 Sports Medicine Australia. Published by Elsevier Ltd. All rights reserved.

## 1. Introduction

Sudden cardiac death (SCD) in athletes, defined as death due to cardiac causes within one hour of symptoms' onset, is the most common medical cause of mortality while training and competing.<sup>1</sup> More than 20 causes of SCD have been identified in young athletes aged 12–35 years, whilst in those  $\geq 35$  years, coronary artery disease predominates.<sup>2</sup> Of the most common causes of SCD in the young athlete population, many have characteristic ECG features, and the ECG can be diagnostic in Wolff–Parkinson–White, long QT and Brugada syndromes.<sup>2</sup> Therefore, the 12-lead ECG is an important screening tool in those athletes at risk of SCD.<sup>3</sup> Indeed, the European Society of Cardiology endorses the use of 12-lead

ECG screening for athletes,<sup>4</sup> as does the International Olympic Committee.<sup>5</sup>

SCD is associated with significant alarm within the broader community due to media attention.<sup>1</sup> This public concern could lead to screening, not only of competitive athletes, but also amateurs; and given the historically high false positive rate of ECG analysis, could cause significant over-investigation and unnecessary distress<sup>1</sup>. Therefore, there has been an imperative to enhance the specificity of ECG criteria with the publication of the 2010 European Society of Cardiology (ESC) recommendations<sup>4</sup>; the 2012 Seattle criteria which were subsequently revised in 2015<sup>6</sup>; and the most recently released 2017 international recommendations for electrocardiographic interpretation in athletes.<sup>3</sup>

The 2017 international recommendations<sup>3</sup> have focused on updating those of the ESC in 2010,<sup>4</sup> which classified ECG changes into either common and physiological, or uncommon and pathological; the latter prompting further diagnostic evaluation. Instead, the new recommendations classify ECG changes into normal, bor-

\* Corresponding author.

E-mail address: [anna.beale@monash.edu](mailto:anna.beale@monash.edu) (A.L. Beale).

derline, or abnormal; where two borderline or one abnormal ECG feature warrants further investigation. The key features that have moved from the pathological/abnormal category include: T-wave inversion, which is considered normal in black athletes in V<sub>1</sub>–V<sub>4</sub> and juvenile athletes <16 years of age in V<sub>1</sub>–V<sub>3</sub>; left atrial enlargement, left axis deviation and right axis deviation, and complete right bundle branch block (RBBB), all of which are now borderline features.

An ideal sport to evaluate the application of the new guidelines is one with both high static but also dynamic components, as this is the type of activity that sees the most cardiac remodelling and ECG changes. Cycling is one such sport.<sup>7</sup> To our knowledge, there is a paucity of data on ECG analysis in professional elite athletes, and often studies lack clarity as to how to define a competitive athlete. This study is novel in investigating truly elite cyclists by focussing on a team of professionals who have attained the “World Tour Licence”, and for whom cardiopulmonary exercise-testing data is available to confirm their physical condition. Furthermore, this is the first study to apply the new international recommendations in such a population.

## 2. Methods

We studied ECGs from a population of elite male professional road cyclists, who were part of a team formed in April 2012. The team was considered a “Continental cycling team” from 2013 to 2014, and then attained the “World Tour License” in 2015, which is the highest level for a road cycling team. They competed in the Tour de France on three occasions, and the Giro d’Italia on two occasions. The athletes are regularly tested for performance enhancing drugs, and thus to our knowledge no such substances were used in this population.

The follow-up of this cycling team was performed by the Geneva University Hospitals. During 4 years between 2012–2015 in the pre-season in December, the athletes had physiological tests at the Cressy Medical Centre in Geneva. As part of the 2013 Union Cycliste Internationale obligatory medical examination for continental cycling teams, they underwent clinical assessments by sports medicine physicians, blood tests and urinary examinations. A resting 12-lead ECG (Cardiovit MS-2010 Schiller AG, Baar, Switzerland; voltage 10 mm/mV, paper speed 25 mm/s, 50 Hz filter) was performed by a cardiologist. Heart rate (Polar Electro, Kempele, Finland); maximal oxygen consumption (VO<sub>2</sub> max) (Mextamax 38 analyser, Cortex Biophysics, Leipzig Germany); and maximal aerobic power (SRM ergometer, Germany) were measured.

ECG analysis was performed by two certified cardiologists experienced in sports cardiology. ECGs were scanned and magnified on a computer in order to improve the accuracy of the analysis. A standard ECG criteria enumeration included analysis of the P wave, RR interval, QRS complex, T wave, PQ interval, and QT interval. In accordance with the 2017 international recommendations for ECG interpretation in athletes, the Bazett’s heart rate formula was used to calculate the QTc interval (QT/√RR) and the Sokolow–Lyon–Index to assess for left (SV<sub>1</sub> + RV<sub>5</sub> or RV<sub>6</sub> > 3.5 mV) or right (RV<sub>1</sub> + SV<sub>5</sub> or SV<sub>6</sub> > 1.1 mV) ventricular hypertrophy. In terms of early repolarization physiological criteria, we separated early repolarisation into anterolateral (V<sub>4</sub>–V<sub>6</sub>), inferior (II, III and aVF), and lateral (I and aVL). We analysed the type of J-wave pattern of early repolarisation: none, notched or slurred, and measured the maximal amplitude in mV, along with the overall ST pattern, 100 ms after the J point. We also classified T wave inversion (TWI) into anterior (V<sub>2</sub>–V<sub>4</sub>), lateral (I and aVL, V<sub>5</sub> and/or V<sub>6</sub>), and inferior (II and aVF). Any ambiguous ECG changes were discussed with other investigators to reach a consensus for each case. We then

**Table 1**

Normal, borderline and abnormal ECG findings. AV, atrioventricular; LBBB, left bundle branch block; LVH, left ventricular hypertrophy; PVC, premature ventricular contraction; RBBB, right bundle branch block; RVH, right ventricular hypertrophy; TWI, t-wave inversion.

Normal ECG findings	N athletes (%)
Increased QRS voltage indicating LVH	28 (65%)
RVH	9 (20.9%)
Incomplete RBBB	18 (41.8%)
Early repolarization	42 (97.6%)
Black athlete repolarization variant	0 (0%)
Juvenile T-wave pattern	0 (0%)
Sinus bradycardia	42 (97.6%)
Sinus arrhythmia	6 (13.9%)
Ectopic atrial rhythm	7 (16.3%)
Junctional escape rhythm	2 (4.6%)
First degree AV block	14 (32.6%)
Mobitz I (Wenckebach) AV block	1 (2.3%)
<i>Total</i>	<i>43 (100%)</i>
Borderline ECG findings	
Left axis deviation	1 (2.3%)
Left atrial enlargement	4 (9.3%)
Right axis deviation	1 (2.3%)
Right atrial enlargement	2 (4.6%)
Complete RBBB	0 (0%)
<i>Total</i>	<i>4 (9.3%)</i>
Abnormal ECG findings	
Pathological TWI	2 (4.6%)
ST-segment depression	0 (0%)
Pathologic Q waves	0 (0%)
Complete LBBB	0 (0%)
Profound nonspecific intraventricular conduction delay	0 (0%)
Epsilon wave	0 (0%)
Ventricular pre-excitation	0 (0%)
Prolonged QT interval	1 (2.3%)
Brugada type I pattern	0 (0%)
Profound sinus bradycardia	0 (0%)
Profound first degree AV block	0 (0%)
Mobitz type II 2 AV block	0 (0%)
Third AV block	0 (0%)
Atrial tachyarrhythmias	0 (0%)
PVC	0 (0%)
Ventricular arrhythmias	0 (0%)
<i>Total</i>	<i>2 (4.7%)</i>
Athletes requiring further Ix	4 (9.3%)

classified the ECG changes into normal, borderline, and abnormal, and further investigations were planned accordingly.<sup>3</sup>

## 3. Results

Baseline characteristics are recorded in Table I, Supplementary material. A total of 103 ECGs were recorded from 43 athletes. All were Caucasian males aged 21–38 years, with a mean age of 28.1 ± 3.9 years, competing for ≥6 months of the year. The BMI ranged from 18.5–26 kg/m<sup>2</sup>. Eleven athletes were followed for 4 years; 5 over 3 years; 17 for 2 years; and 10 for 1 year (mean years followed 2.4 ± 1.1). The primary reason for leaving the study was a change in cycling team. Maximal aerobic power results and VO<sub>2</sub> max results from 2012 to 2015 are listed in Table I (Supplementary material). The average VO<sub>2</sub> max was 66.4 ± 7.1 ml/min/kg, consistent with a high level of aerobic training.

We recorded 102 ECGs in 43 athletes with normal variations, 10 ECGs in 4 athletes with borderline changes, and 2 ECGs in 2 athletes with abnormal variations, as detailed in Table 1.

The most common normal variations seen were bradycardia (97.6%), left ventricular hypertrophy (LVH) (65%) and early repolarisation (97.6%). Normal variations did not tend to vary between years in athletes who had multiple years of follow-up.

Positive Sokolow criteria for left ventricular hypertrophy was noted in 28 (65%) of athletes across 61 ECGs (59.2%), with the high-

**Table 2**  
Early repolarization patterns.

ECG leads	ECGs, n (%)	Notched t-wave, n (%)	Terminal QRS slurring, n (%)	ST elevation	Descending/horizontal pattern
V <sub>4</sub> –V <sub>6</sub>	97 (94.2)	20 (19.4)	2 (1.9)	75 (72.8)	3 (2.9)
I, aVL	6 (5.8)	1 (1.9)	0 (0)	5 (4.8)	0 (0)
II, III, aVF	26 (25.2)	2 (1.9)	10 (9.7)	12 (11.6)	1 (0.97)

**Table 3**  
ECG findings necessitating further investigation. LAVI, left atrial volume index; LAE, left atrial enlargement; RAE, right atrial enlargement; TWI, T wave inversion; LV, left ventricular.

Gender	Age (years)	BMI (kg/m <sup>2</sup> )	VO <sub>2</sub> max (ml/kg/min)	MAP (Watt)	ECG findings	TTE findings
Male	26	22.3	68.4	430	LAE RAE	Mild RAE (right atrial area 24 cm <sup>2</sup> )
Male	29	22	74.4	405	LAE RAE	Mild LAE (LAVI 35.5 ml/m <sup>2</sup> ) and mild LV wall thickening (posterior LV wall thickness 11 mm)
Male	24	18.8	69.4	370	TWI V <sub>2</sub> –V <sub>4</sub> QTc >= 470 ms	Mild LAE (LAVI 41.8 ml/m <sup>2</sup> )
Male	34	26	54.0	419	TWI V <sub>2</sub> –V <sub>4</sub>	Mild bi-atrial dilatation (LAVI 36 ml/m <sup>2</sup> , right atrial area 23.6 cm <sup>2</sup> )

est index (S wave in V<sub>1</sub> + R wave in V<sub>5-6</sub>) recorded as 58 mm (normal <35 mm). Right ventricular hypertrophy (RVH) was identified in 9 (20.9%) of athletes. Echocardiography, performed biennially in all athletes as part of routine screening, revealed an elevated left ventricular mass index in 11 (26%) of athletes, with a sensitivity and specificity of electrocardiographically determined LVH in our cohort of 73% and 34% respectively.

42 (97.6%) of the athletes met early repolarisation criteria, which were predominantly seen in lateral leads; 41 (95.3%) of athletes had early repolarisation in V<sub>4</sub>–V<sub>6</sub>. Almost all ECGs had an ascending pattern 100 ms after the J point (Table 2).

4 (9.3%) of the athletes met the criteria for left atrial enlargement, 2 (4.7%) of the athletes demonstrated left axis deviation, and 1 (2.3%) athlete had right atrial enlargement (right and left atrial enlargement demonstrated in Fig. S1, Supplementary material). No complete RBBB was found. 2 (4.7%) of the athletes had ECGs exhibiting 2 coexistent borderline variations, prompting further investigation.

Two ECGs in two different athletes met the criteria for pathological changes. Both had TWI in the anterior precordial leads, and one had QTc prolongation (Fig. S2, Supplementary material). This athlete saw resolution of the QTc prolongation in subsequent ECGs in following years but not the TWI, whilst the other athlete had resolution of the TWI and no further abnormal findings (Table 3).

As described above, two athletes had two co-existent borderline variations, and two athletes had abnormal variations. Therefore 4 athletes (9.3%) were further investigated with transthoracic echocardiography, as highlighted in Table 3. The findings were mild right or left atrial dilatation without other concerns in 3; and the 4th had mild left ventricular wall thickening in addition to mild left atrial dilatation. This implies a false positive rate of 9.3% for the ECG assessment, albeit with a short period of follow-up.

The consistency of these concurrent borderline or abnormal ECG findings across each athlete's follow-up period for these 4 athletes was also assessed. The athletes with TWI had 3 and 4 years of follow-up, however TWI according to the 2017 international recommendations was only identified in one ECG. Interestingly, applying the 2010 recommendations found TWI in all 4 years of follow up for one, and 2 out of 3 years for the other. Similarly, regarding the two athletes with two concurrent borderline findings; these only coexisted in one out of the 3 or 4 years that they were followed for. In both cases, these athletes had isolated LAE in one year, and the remaining year(s) were normal.

#### 4. Discussion

We believe that this is the first study to be published following the release of the 2017 international recommendations for ECG interpretation in endurance athletes. We are aware of one paper studying professional Basketball players,<sup>8</sup> which surprisingly found higher rates of concurrent borderline or abnormal findings.

In our study, the application of these new guidelines resulted in 4 cases requiring further investigation, all of which were negative echocardiography examinations. This gives a false positive rate of 9.3%, marginally lower than reports from the application of the previous recommendations, however it must be noted that the false positive rate is based on a very short follow-up time frame, and it is possible ECG findings may have preceded echocardiographic abnormalities. Weiner et al. applied the 2010 guidelines to the assessment of university athletes participating in a range of sports of predominantly static components, and found a 10% false positive rate of ECG screening.<sup>9</sup> This suggests improved specificity, albeit marginal, of the new guidelines, however the difference in sporting activity studied may affect this result.

Our study applied the new international recommendations for ECG analysis in athletes to an elite professional cycling team, and found that "normal", or physiological, changes were ubiquitous. Not surprisingly, the majority of cyclists had sinus bradycardia and early repolarization abnormalities, both present in 42 (97.6%) of athletes, which are common consequences of increased vagal tone in athletes.<sup>10</sup> Early repolarization abnormalities are considered to be benign according to international consensus.<sup>3</sup> This is despite literature suggesting that certain morphologies of early repolarization may pose an increased risk of malignant arrhythmias.<sup>11</sup>

This association between early repolarization and ventricular fibrillation is seen mostly when the early repolarization is in the inferior leads.<sup>11</sup> In the athletes in this study, the vast majority of early repolarization was seen in the lateral leads (94.2%), with 25.2% in the inferior leads; only 1 ECG showed the "highest risk" combination of horizontal or descending ST segment, and location of early repolarisation in the inferior leads. Therefore, although early repolarization was almost ubiquitous in our population, the pattern is predominantly one of lower risk. Furthermore there is insufficient evidence at present to suggest that early repolarization patterns in isolation are indicative of any underlying pathology, and therefore these athletes can be reassured.<sup>3</sup>

Another common normal variation found in our athletes was LVH, present in 65% on ECG, although only 26% on echocardiography, consistent with other reports there is a poor correlation between LVH on the ECG and LVH on cardiac imaging in young populations.<sup>12,13</sup> This high prevalence of LVH on the ECG is comparable to similar studies of cyclists,<sup>14</sup> suggesting that they may have higher left ventricular mass compared to athletes in other sports, such as football players and canoeists. The high static and dynamic demands of cycling, with a requirement to enhance cardiac output for a prolonged period of time, could explain the resultant LVH.

Another common finding in our elite cyclists was RVH, present in 20.9% of athletes, a rate slightly higher than other studies of young athletes.<sup>15</sup> Right ventricular remodelling is typically seen in endurance athletes, and increases with race duration.<sup>16</sup> The right ventricle experiences greater increases in ventricular load with exercise, and therefore is more susceptible to an increase in ventricular dimensions.<sup>16</sup> Interestingly in our study, LVH was far more common than RVH. However, we did not include echocardiographic measures of right ventricular size, and therefore we were not able to compare echo-based measures of RVH to LVH. Features suggestive of right ventricular pathology include anterior TWI, which may be suggestive of arrhythmogenic right ventricular cardiomyopathy; or changes such as right axis deviation, ST-depression, right atrial enlargement and TWI, which may indicate pulmonary hypertension. Given the high frequency of RVH in athletes, the presence of these features is required to warrant further investigation.<sup>17</sup>

Borderline changes were identified in 12 ECGs, most commonly atrial enlargement and left axis deviation. Endurance athletes have a 2–7 fold higher rate of atrial fibrillation<sup>18,19</sup>; which is associated with increased left atrial diameter and volume,<sup>19</sup> suggesting that these structural changes may predispose to atrial arrhythmias. However this association between endurance sport and atrial fibrillation derives from cohorts with a mean age of 57 and 39 years, and is therefore not reflective of our study population.

Only two athletes (4.7%) ECGs met the criteria for pathological findings, with TWI and a prolonged QTc interval, similar to a large study of athletes competing in multiple different sports.<sup>20</sup> The overall prevalence of abnormal ECG findings is lower than comparable studies using the 2010 recommendations, such as a study by Wilson et al., finding “uncommon” ECG changes in 5.8% of Caucasian athletes.<sup>21</sup> This study primarily included footballers and basketballers, and therefore the prevalence in cyclists could be expected to be higher. Also using the 2010 recommendations, an Australian study of endurance athletes participating in a variety of sports found a substantial prevalence of abnormal findings, with 19% affected.<sup>22</sup> This may indicate that the updated criteria do have the desired effect of increasing the specificity of the abnormal ECG criteria. Furthermore, we found that concurrent borderline or abnormal findings were only present in one of the 3–4 years that the athletes were followed for, whereas applying the 2010 recommendations found abnormalities in more than twice as many of the ECGs. This, again, may suggest greater specificity of the new guidelines.

Regarding TWI, there is no discrimination in the 2017 recommendations with regard to the leads in which this abnormality is found; all are considered pathological unless in black or adolescent athletes. In our athletes, the TWI was in V<sub>2</sub>–V<sub>4</sub>. The echocardiograms in both of these patients simply revealed mild bi-atrial dilatation. Interestingly, studies have suggested that TWI in inferior or lateral leads is associated with a higher risk of ischaemic heart disease, cardiomyopathy, aortic valve disease, systemic hypertension and left ventricular non-compaction.<sup>23,24</sup> Furthermore, in our patients, TWI was associated with convex ST segment elevation/J point elevation (Fig. S2), which may indicate ‘physiologic’ rather than ‘pathologic’ TWI.<sup>25</sup> Perhaps, then, our athletes have a more benign form of TWI; or possibly it may indicate an early expression

of an underlying structural change that is yet to be evident on cardiac imaging.<sup>26</sup> Furthermore, it must be highlighted that the resting ECG is insufficient for detection of premature coronary disease, and therefore is inadequate for screening for this purpose.<sup>3</sup>

One of our athletes had QT segment prolongation on one ECG, however this resolved on subsequent ECGs. Whilst a study by Basavarajiah et al. suggested that a QTc of >500 ms is highly suggestive of long QT syndrome, they also commented that an isolated long QT segment can be an effect of delayed repolarization as a result of increased left ventricular mass.<sup>27</sup> Therefore, this may explain the transient prolongation of QT interval in this case. Alternatively, it could have been purely a spurious result.

There are important limitations of this study. The first is the small sample size, a result of following a single team of cyclists rather than athletes from multiple different sports. The second is that for one year of the analysis, athletes had insufficient time between their physiological tests and their ECG, and therefore the detection of ECG findings may have been impaired. All tests were performed in December in a period where the athletes were not as trained compared to the summer period, however the data on physiological testing suggested that they maintained a high level of fitness during the assessment period. Additionally, cyclists may have been part of a different team prior to joining this elite team, and therefore those with ECG abnormalities would be likely to have already been screened out. This introduces the possibility of selection bias.

A clear limitation to this study is the lack of heterogeneity of the athletes in terms of race and gender; all were Caucasian males. This is not unexpected in the context of a gross overrepresentation of white athletes in professional cycling. There is significant evidence describing different patterns of cardiac remodelling in athletes of African origin.<sup>21,28,29</sup> There are also sex differences in left ventricular adaption to exercise; women have lower rates of concentric remodelling or hypertrophy in response to exercise, with lower left ventricular mass but a greater propensity for eccentric remodelling.<sup>30</sup> Therefore these factors must be taken into consideration when assessing athletes of different gender and race.

## 5. Conclusion

We analysed a small team of Caucasian male professional elite cyclists according to the newly released 2017 international recommendations for electrocardiographic interpretation in athletes, and found universal normal ECG variations, mainly bradycardia and early repolarization. The presence of abnormal ECG findings was lower than comparable studies using earlier guidelines for ECG assessment, and the false positive rate was modestly reduced. This suggests enhanced specificity of the new recommendations, which may increase clinicians’ confidence in the guidelines. Further study of the application of these new guidelines to diverse sporting activities, ethnicities, and gender, ideally with larger sample sizes, should be pursued to consolidate our findings.

## Practical implications

- This is the first study to apply the new guidelines for electrocardiogram assessment in elite professional endurance athletes in practice.
- In the study, there were very few abnormal or borderline electrocardiogram findings, and only 9.3% required further investigation.
- This suggests robust specificity of the new guidelines, albeit applied in a small cohort, and may improve clinicians’ confidence in using the guidelines in clinical practice.

## Acknowledgement

No acknowledgements to make, all contributors are listed as authors.

## Appendix A. Supplementary data

Supplementary data associated with this article can be found, in the online version, at <https://doi.org/10.1016/j.jsams.2018.06.017>.

## References

- Koester MC. A review of sudden cardiac death in young athletes and strategies for preparticipation cardiovascular screening. *J Athl Train* 2001; 36:197–204.
- Chandra N, Bastiaenen R, Papadakis M et al. Sudden cardiac death in young athletes: practical challenges and diagnostic dilemmas. *J Am Coll Cardiol* 2013; 61:1027–1040.
- Sharma S, Drezner JA, Baggish A et al. International recommendations for electrocardiographic interpretation in athletes. *Eur Heart J* 2017.
- Corrado D, Pelliccia A, Heidbuchel H et al. Recommendations for interpretation of 12-lead electrocardiogram in the athlete. *Eur Heart J* 2010; 31:243–259.
- Bille K, Figueiras D, Schamasch P et al. Sudden cardiac death in athletes: the Lausanne recommendations. *Eur J Cardiovasc Prev Rehabil* 2006; 13:859–875.
- Drezner JA, Ackerman MJ, Anderson J et al. Electrocardiographic interpretation in athletes: the 'Seattle criteria'. *Br J Sports Med* 2013; 47:122–124.
- Mitchell JH, Haskell W, Snell P et al. Task force 8: classification of sports. *J Am Coll Cardiol* 2005; 45:1364–1367.
- Waase MP, Mutharasan R, Whang W et al. Electrocardiographic findings in national basketball association athletes. *JAMA Cardiol* 2018; 3:69–74.
- Weiner RB, Hutter AM, Wang F et al. Performance of the 2010 European Society of Cardiology criteria for ECG interpretation in athletes. *Heart* 2011; 97:1573–1577.
- Drezner JA, Fischbach P, Froelicher V et al. Normal electrocardiographic findings: recognising physiological adaptations in athletes. *Br J Sports Med* 2013; 47:125–136.
- Haissaguerre M, Derval N, Sacher F et al. Sudden cardiac arrest associated with early repolarization. *N Engl J Med* 2008; 358:2016–2023.
- Sathanandam S, Zimmerman F, Davis J et al. Abstract 2484: ECG screening criteria for LVH does not correlate with diagnosis of hypertrophic cardiomyopathy. *Circulation* 2016; 120:S647.
- Crow RS, Prineas RJ, Rautaharju P et al. Relation between electrocardiography and echocardiography for left ventricular mass in mild systemic hypertension (results from treatment of mild hypertension study). *Am J Cardiol* 1995; 75:1233–1238.
- Iglesias Cubero G, Batalla A, Rodriguez Reguero JJ et al. Left ventricular mass index and sports: the influence of different sports activities and arterial blood pressure. *Int J Cardiol* 2000; 75:261–265.
- Zaidi A, Ghani S, Sheikh N et al. Clinical significance of electrocardiographic right ventricular hypertrophy in athletes: comparison with arrhythmogenic right ventricular cardiomyopathy and pulmonary hypertension. *Eur Heart J* 2013; 34:3649–3656.
- La Gerche A, Burns AT, Mooney DJ et al. Exercise-induced right ventricular dysfunction and structural remodelling in endurance athletes. *Eur Heart J* 2012; 33:998–1006.
- Claessen G, Brosnan M, La Gerche A et al. Signs of RV overload on the athlete's ECG. *J Electrocardiol* 2015; 48:399–406.
- Andersen K, Farahmand B, Ahlbom A et al. Risk of arrhythmias in 52 755 long-distance cross-country skiers: a cohort study. *Eur Heart J* 2013; 34:3624–3631.
- Molina L, Mont L, Marrugat J et al. Long-term endurance sport practice increases the incidence of lone atrial fibrillation in men: a follow-up study. *Europace* 2008; 10:618–623.
- Pelliccia A, Culasso F, Di Paolo FM et al. Prevalence of abnormal electrocardiograms in a large, unselected population undergoing pre-participation cardiovascular screening. *Eur Heart J* 2007; 28:2006–2010.
- Wilson MG, Chatard JC, Carre F et al. Prevalence of electrocardiographic abnormalities in West-Asian and African male athletes. *Br J Sports Med* 2012; 46:341.
- Brosnan M, La Gerche A, Kalman J et al. Prevalence of significant ECG abnormalities in 1,072 elite Australian athletes. *Paper presented at: ESC Congress*, 2012.
- Pelliccia A, Di Paolo FM, Quattrini FM et al. Outcomes in athletes with marked ECG repolarization abnormalities. *N Engl J Med* 2008; 358:152–161.
- Corrado D, Pelliccia A, Bjornstad HH et al. Cardiovascular pre-participation screening of young competitive athletes for prevention of sudden death: proposal for a common European protocol. Consensus Statement of the Study Group of Sport Cardiology of the Working Group of Cardiac Rehabilitation and Exercise Physiology and the Working Group of Myocardial and Pericardial Diseases of the European Society of Cardiology. *Eur Heart J* 2005; 26:516–524.
- 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; 37:2515–2527.
- McKenna WJ, Spirito P, Desnos M et al. Experience from clinical genetics in hypertrophic cardiomyopathy: proposal for new diagnostic criteria in adult members of affected families. *Heart* 1997; 77:130–132.
- Basavarajiah S, Wilson M, Whyte G et al. Prevalence and significance of an isolated long QT interval in elite athletes. *Eur Heart J* 2007; 28:2944–2949.
- Basavarajiah 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; 51:2256–2262.
- Di Paolo FM, Schmied C, Zerguini YA et al. The athlete's heart in adolescent Africans: an electrocardiographic and echocardiographic study. *J Am Coll Cardiol* 2012; 59:1029–1036.
- Finocchiaro G, Dhutia H, D'Silva A et al. Effect of sex and sporting discipline on LV adaptation to exercise. *JACC Cardiovasc Imaging* 2017; 10:965–972.