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Cost implications of using different ECG criteria for screening young athletes in the United Kingdom

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Cost Implications of Using Different ECG Criteria for Screening Young Athletes in the United Kingdom

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ABSTRACT

Background

High false positive rates and the subsequent cost of additional investigations provide a major obstacle to screening young athletes for cardiac disease with an electrocardiogram (ECG). However, the actual cost of ECG screening has never been assessed systematically in a large cohort of athletes.

Objective

This study investigated the financial implications associated with ECG interpretation in athletes according to the 2010 European Society of Cardiology (ESC) and the more contemporary Seattle and refined ECG interpretation criteria.

Methods

Between 2011 and 2014, 4,925 previously unscreened athletes aged 14-35 years were prospectively evaluated with history, physical examination and an ECG interpreted with the 2010 ESC recommendations. Athletes with abnormal results underwent secondary investigations, the costs of which were based on the UK National Health Service Tariffs. The impact on cost after applying the Seattle and refined criteria was evaluated retrospectively.

Results

1,072 (21.8%) athletes revealed an abnormal ECG based on the 2010 ESC recommendations. 11.2% athletes required echocardiography, 1.7% exercise stress test, 1.2% Holter, 1.2% cardiac MRI and 0.4% other tests. The Seattle and refined criteria reduced the number of positive ECGs to 6.0% and 4.3% respectively. 15

(0.3%) athletes were diagnosed with potentially serious cardiac disease using all three criteria. The overall cost of de-novo screening using the 2010 ESC recommendations amounted to $539,888, equating to $110 per athlete and $35,993 per serious diagnosis. The Seattle and refined criteria reduced the cost to $92 and $87 per athlete screened and $30,251 and $28,510 per serious diagnosis respectively, representing a 21% cost saving per athlete screened.

Conclusion

Contemporary ECG interpretation criteria are associated with significant cost reductions for a de-novo screening program in athletes which may be cost permissive for some financially endowed sporting organisations.

KEY WORDS

Athlete, Sudden cardiac death, Electrocardiogram, Pre-participation screening

ABBREVIATIONS

ECG: Electrocardiography

ESC: European Society of Cardiology

MRI: Magnetic resonance imaging

INTRODUCTION

Sudden cardiac death in sport is a rare but highly visible event and the identification of young athletes harbouring potentially serious cardiac disease is an important focus within the medical community. Pre-participation screening with a 12 lead electrocardiogram (ECG) is effective for detecting ion channel diseases and congenital accessory pathways and some electrical anomalies also raise suspicion of the main cardiomyopathies implicated in sudden cardiac death (1,2,3). The 30 year old nationally sponsored Italian cardiac screening program with ECG has reported a substantial reduction in the prevalence of sudden cardiac death in young athletes since its inception (4). Although both the European Society of Cardiology (ESC) (5) and the International Olympic Committee (6) endorse ECG screening in athletes, an important concern regarding such practice is the unacceptably high false positive rate and subsequent cost generated by additional investigations to confirm or refute cardiac disease. The 2010 ESC recommendations for ECG interpretation in athletes are associated a false positive rate ranging from 9% to 22% (3,4,7,8).The Seattle criteria has significantly improved the specificity of ECG screening criteria for detecting cardiac disease associated with sudden cardiac death predominantly by accounting for specific benign repolarisation anomalies associated with black ethnicity and designating less conservative limits for an abnormal QT interval (2,7,8). More recent refined criteria have been associated with a further reduction in the false positive rate for detecting cardiac disease associated with sudden cardiac death without compromising sensitivity (7). Whether modification of the ECG interpretation criteria in young athletes is associated with a significant cost reduction has not been investigated.

This study compared the costs associated with additional investigations triggered by the ESC, Seattle and refined ECG criteria in a large cohort of young athletes in the United Kingdom (UK) undergoing cardiovascular screening for the first time.

METHODS

Setting

The UK does not support a state-sponsored screening program in athletes. However, the charitable organisation Cardiac Risk in the Young established a cardiac screening program for young individuals in 1997 that also serves many professional sporting organisations in the UK (9). Up to 1500 athletes aged 14-35 years from numerous regional or national sporting squads are assessed annually. The screening program is overseen by the senior author. The cost of the initial screening evaluation is incurred by the sporting organisation responsible for the athlete.

Athletes

Between 2011 and 2014, 5,374 consecutive athletes were screened as part of a mandatory requirement of their respective sporting organisations. 449 athletes been assessed previously as part of their clubs' screening policy. In this group, 36 athletes (8%) had previously undergone further investigations beyond the ECG and cardiac disease was excluded. We report data from 4,925 athletes who were previously unscreened with ECG. The dataset includes 1,026 athletes screened in 2011/12 who formed part of a previous investigation comparing the efficacy of major ECG interpretation criteria for detecting cardiac disease (7). All athletes were initially evaluated by experienced sports cardiologists. Athletes were defined as individuals

competing in organized team or individual sports at regional, national, or international level with a high premium on athletic excellence. Ethnicity/race was determined by self-report.

Preliminary Investigations in Athletes undergoing Pre-participation Screening

<u>Health Questionnaire</u>

The health questionnaire inquired about cardiac symptoms, past medical history, drug history, and family history of premature (<40 years old) cardiac disease or sudden cardiac death.

<u>Physical Examination</u>

Physical examination consisted of measurement of height, weight, radial and femoral pulses, brachial blood pressure measurements in the dominant arm, precordial examination at 45^0, and assessment for features of Marfan syndrome (10). Abnormal findings triggering further investigation included a blood pressure >140/90 mmHg on three consecutive occasions, radio-femoral delay, stigmata of Marfan Syndrome, a pathological murmur, widely split second heart sound or a third/fourth heart sound.

<u>Electrocardiography</u>

A resting 12-lead ECG was performed using a Philips Pagewriter Trim III recorder (Philips, Bothell, Washington) with a paper speed of 25 mm/s and amplification of 0.1 mV/mm. P-, Q-, R-, S-, and T-wave voltages; ST-segments; QRS duration; PR-interval and QT-intervals were measured using callipers. The longest QT interval value was considered as the absolute QT and was corrected for heart rate with the Bazett's formula (11) The 2010 ESC recommendations were initially used to interpret the ECG because they were the only recommendations available at the time of

initiation of the study (3). The Seattle criteria and refined criteria for ECG interpretation in athletes were applied to the cohort retrospectively (Table 1) (2,7).

T-wave inversion in leads V1-3 in asymptomatic athletes aged >14<16 years old was considered a normal variant in the absence of a relevant family history irrespective to the ECG criterion used (12). Such individuals were advised to have a repeat ECG at age 16 years with view to further investigation if the juvenile pattern persisted.

Further Investigations and Outcome

The requirement for further investigations were determined by the screening sports cardiologists and was dependent on symptoms, relevant family history, abnormal physical examination or abnormal ECG. Athletes requiring secondary investigations were referred to hospitals within their geographic vicinity with a report that specified the abnormal findings, included the ECG, diagnosis in question, and a proposed investigation protocol based on our long standing experience of investigating athletes and patients with inherited cardiac disease (13).

Concurrent with our clinical practice, we used less conservative limits for abnormal QT intervals than those considered by the 2010 ESC recommendations when advising the need for further investigations. This decision was based on high false positive rates and very low predictive value for the limits imposed by the 2010 ESC recommendations (1,14,15). Specifically, we recommended further investigations in asymptomatic male athletes with an isolated QT interval ≥ 470 msec and in asymptomatic females with a QT interval ≥ 480 msec, and an isolated QT interval ≤ 320 msec in all athletes.

Secondary investigations were conducted by attending cardiologists and were aimed at confirming or refuting a diagnosis of cardiac disease. The ultimate decision relating to the type and number of secondary investigations was made by the attending cardiologist. Investigations included echocardiography, exercise stress testing, 24-hour ECG monitoring (Holter), 24 hour blood pressure monitoring, signal average ECG, cardiac magnetic resonance imaging (MRI), computed tomography, pharmacological provocation testing or electrophysiological studies. Serious cardiac diseases were defined as those implicated in exercise-related sudden cardiac death (16). Data relating to further investigations and the final diagnosis was obtained through communication with the club doctor using a questionnaire at 6 monthly intervals.

Financial Analysis

Costs were incurred in Great Britain pounds (£), but are presented in US dollars ($) with a currency exchange rate of £1=$1.52 at the time of manuscript preparation.

The initial pre-participation screening tests (history, physical examination and ECG) were performed at a subsidised cost of $53 per athlete screened. The costs of secondary investigations were calculated based on the 2014/2015 UK National Health Service tariff payment system (Table 2) (17). There is currently no national rebate for pharmacological testing for Brugada syndrome, or for 24 hour blood pressure monitoring or signal average ECG. Therefore we used the fee for these procedures at our institute for the analysis. The fee for genetic testing was obtained from a national molecular centre for clinical genetics in Oxford (UK) (18). The impact on cost after application of the Seattle and refine criteria was evaluated retrospectively.

Statistics

Statistical analyses were performed using the SPSS software, version 17 (SPSS, Inc., Chicago, Illinois). Variables were tested for normality using the Kolmogorov-Smirnov test. Group differences of normally distributed data were tested with the t-test and expressed as mean (± standard deviation). Group differences of proportions were tested with the use of chi-square or Fisher's exact tests. Costs between ECG criteria were compared using paired rank sum testing. Significance was defined as $p < 0.05$.

Ethics

Ethical approval was granted by the Essex 2 Research Ethics Committee. Written consent was obtained from individuals ≥16 years of age and from a parent/ guardian for those <16 years of age.

RESULTS

Demographics

Athletes were aged 19.9 ± 5 years (14-35 years). The majority were male (n=4,068; 83%) and white (n=4,025; 85%). 444 athletes (9%) were of African or Afro-Caribbean origin and 276 (5%) consisted of other ethnicities. 4,230 (85.9%) athletes were aged ≥16 years. Athletes competed in a total of 26 different sporting disciplines (predominantly rugby (53%), soccer (13%) and swimming (5%)) and exercised for 15.6 ± 7 hours per week.

History and Physical Examination

61 (1.2%) athletes revealed abnormalities on the health questionnaire. Of these, 43 athletes reported symptoms that could have been consistent with cardiac disease according to the screening cardiologist (palpitations n=18, chest pain n=10, syncope n=8, and dyspnoea n=7) and 18 had a significant family history (cardiomyopathy n=6, channelopathy n=1, unexplained premature sudden cardiac death n=11). 18 (0.4%) athletes had an abnormal physical examination (cardiac murmur n=12, blood pressure >140/90 n=4 and stigmata of Marfan syndrome n=2).

ECG Interpretation

1,072 (21.8%) athletes exhibited ≥1 ECG abnormality according to the 2010 ESC recommendations (inclusive of the original criteria for an abnormal QT interval) (3). 295 (6.0%) athletes had an abnormal ECG with reference to the Seattle criteria, equating to a 73% reduction compared to the 2010 ESC recommendations ($p<0.0001$). Application of the refined criteria reduced the number of abnormal ECGs to 210 (4.3%). Compared to the 2010 ESC recommendations and Seattle criteria, this represented an 80% ($p<0.0001$) and 29% ($p<0.0001$) reduction in the number of abnormal ECGs respectively (Figure 1).

The predominant factors in reducing the number of abnormal ECGs between the 2010 ESC recommendations and the Seattle and refined criteria were the number of athletes considered to exhibit an abnormal QT interval (13.6% vs. 0.4%) or abnormal T-wave inversion (5.1% vs. 1.6% and 3.0% respectively).

The prevalence of abnormal T-wave inversions according to the 2010 ESC, Seattle and refined criteria was 251 (5.1%), 81 (1.6%) and 149 (3.0%) respectively (Figure 1). The lower number of athletes considered to have abnormal anterior T-wave

inversion (beyond V1 for refined and beyond V2 for Seattle) accounted for the difference between the Seattle and refined ECG criteria (0.8% vs. 2.2%; p<0.0001).

Further Evaluation

79 (1.6%) athletes required further investigations for symptoms, family history or abnormal physical examination and 502 (10.2%) athletes were referred for an abnormal ECG based on the 2010 ESC recommendations adapted for less conservative criteria for abnormal QT intervals. The difference in the actual number of athletes with an ECG abnormality (n=1,072) and the number of athletes referred for further investigations for an ECG abnormality (n=502) reflected our personal practice to not investigate asymptomatic athletes with an isolated long QT interval <470 msec (males) or <480 msec (females) (n=300), or a short QT interval >320<380 msec (n=270). Overall, 581 (11.8%) of the 4,925 athletes were referred for further investigations after preliminary screening.

The authors received completed questionnaires relating to further investigations to confirm (or refute) diagnosis of disease in all 581 athletes. 550 (11.2%) athletes underwent transthoracic echocardiography, 85 (1.7%) underwent exercise stress testing, 59 (1.2%) underwent Holter monitoring, 61 (1.2%) underwent cardiac MRI and 18 (0.4%) underwent a combination of 24 hour blood pressure monitoring, signal average ECG, electrophysiological studies, trans-oesophageal echocardiography, computed tomography or pharmacological provocation testing for Brugada syndrome to confirm (or refute) diagnosis of cardiac disease (Table 2).

Application of the Seattle criteria and refined criteria would result in 374 (7.6%) and 289 (5.9%) athletes requiring further investigation, representing a 35% and 50% reduction respectively compared to the 2010 ESC recommendations adapted for less conservative criteria for an abnormal QT interval (Table 2).

None of the 449 athletes that had previously undergone cardiovascular screening required additional investigation following health questionnaire, physical examination and ECG.

Identification of Cardiac Pathology

Following further cardiac investigation, 15 (0.3%) athletes were diagnosed with cardiac pathology implicated in sudden cardiac death in young athletes. Specifically, 6 athletes were diagnosed with hypertrophic cardiomyopathy, 3 with long QT syndrome and 6 with the Wolff-Parkinson-White Syndrome ECG pattern. All 15 athletes were asymptomatic and diagnosed following an abnormal ECG irrespective of the ECG interpretation criterion used. The 6 athletes with hypertrophic cardiomyopathy displayed T-wave inversions in the lateral or inferior-lateral leads, and were diagnosed by a combination of echocardiography and cardiac MRI. The 3 athletes with long QT syndrome were diagnosed on the basis of a prolonged QT interval (≥ 480msec) and exercise stress testing (Table 3).

16 (0.3%) athletes were diagnosed with other structural cardiac abnormalities (bicuspid aortic valve n=12, atrial septal defect n=2, mitral valve prolapse n=2). Of these, 8 (50%) were diagnosed by abnormal physical examination whilst 8 (50%) were detected following investigation for an abnormal ECG by the 2010 ESC recommendations. The Seattle criteria would have failed to detect 2 athletes and the

refined criteria would not have identified 5 athletes with these conditions (supplemental table).

Financial Analysis

Preliminary Screening

The initial cost of screening with history, physical examination and ECG was $53 per athlete which equates to a total cost of $261,025 for the 4,925 athletes screened.

Evaluation after Pre-participation Screening

The cost of evaluating 79 athletes with an abnormal history or examination amounted to $39,623. The cost of secondary investigations following an abnormal ECG according to the 2010 ESC recommendations adapted for less conservative criteria for abnormal QT interval was $239,240. Therefore, the overall cost of comprehensive cardiovascular evaluation for the entire cohort of previously unscreened athletes was $539,888 which equates to a cost of $110 per athlete screened and a cost of $17,416 per diagnosis of a cardiac condition and $35,993 per cardiac condition associated with sudden cardiac death. Adherence to the original 2010 ESC recommendations for an abnormal QT interval would have resulted in an estimated cost of $157 per athlete on the assumption that all athletes would have had an exercise test and Holter monitor.

Application of the Seattle criteria reduced the cost of secondary investigations to $153,120. The overall cost for the cohort would have been $453,768, equating to a cost of $92 per athlete screened and a cost of $15,647 per diagnosis of a cardiac condition and $30,251 per serious diagnosis. The $17 reduction per athlete screened represents a saving of 16% compared to screening with the 2010 ESC

recommendations (p<0.0001).The refined criteria reduced the cost of secondary investigations to $127,009 resulting in an overall cost of $427,657 and equating to a cost of $87 per athlete screened and a cost of $16,448 per diagnosis of a cardiac condition and $28,510 per diagnosis associated with sudden cardiac death. This figure represents a cost saving of $23 (21%) per athlete compared to the 2010 ESC recommendations (p<0.0001) and $5 (5%) per athlete compared to the Seattle criteria (p=0.114). Investigation for T-wave inversions accounted for 25% of the total cost of pre-participation screening with the 2010 ESC recommendations, 14% for the Seattle criteria and 21% of the refined criteria (Central illustration).

Sensitivity Analysis

We performed a sensitivity analysis investigating the impact on cost per athlete screened with the refined criteria with the following variables: the initial non-invasive risk stratification tests (exercise stress test (n=10) and Holter (n=8)) at the time of diagnosis of serious disease, genetic testing for long QT syndrome (n=3) and hypertrophic cardiomyopathy (n=6), electrophysiological studies and radiofrequency ablation for 4 athletes with Wolff-Parkinson-White syndrome ECG pattern, and the inclusion of the 449 athletes who had previously undergone cardiovascular screening (Figure 2). The inclusion of non-invasive risk stratification tests would result in an additional $1 per athlete screened. Genetic testing for long QT syndrome and hypertrophic cardiomyopathy would result in a further $2 per athlete screened. Electrophysiological studies and radiofrequency ablation for Wolff-Parkinson-White syndrome ECG pattern would add a further $2 per athlete. Conversely the inclusion of the athletes that had been previously screened would reduce the cost per athlete screened by $3.

DISCUSSION

This study evaluated the financial implications of ECG based screening using different ECG interpretation criteria in almost 5,000 young athletes. Based on the diagnosis of a cardiac condition in 31 (0.6%) athletes, the overall cost of ECG screening with the 2010 ESC recommendations adapted for less conservative criteria for an abnormal QT interval equated to $110 per athlete screened and $17,416 per condition diagnosed ($35,993 per condition implicated in sudden cardiac death). The Seattle and refined criteria would reduce the cost per athlete screened by up to 21% without compromising the sensitivity for detecting athletes at risk of sudden cardiac death. The additional cost of non-invasive risk stratification at the time of diagnosis, gene testing and electrophysiological studies and radiofrequency ablation for Wolff-Parkinson-White syndrome ECG pattern amount to an additional $5 per athlete. This figure represents a small cost increment of 5% based on the refined criteria and is still $18 (16%) cheaper than the cost of diagnosis alone using the adapted 2010 ESC recommendations.

Trends in Investigations

Following preliminary assessment, 11.2% of the athletes required transthoracic echocardiography, 1.7% exercise stress testing, 1.2% Holter monitoring, 1.2% cardiac MRI and 0.4% required other tests respectively (Table 2). To our knowledge, there are only three studies describing the extent of secondary investigations following abnormalities on history, physical examination or ECG (4,19,20). In the Veneto region of Italy, 9% of 42,386 athletes required further investigation due to an ECG abnormality; overall further investigations included echocardiography in 9.2%, exercise stress testing in 3.1%, Holter monitoring in 1.2%, and a combination of

cardiac MRI or more invasive testing such as electrophysiological studies or angiography in 0.2%. Whilst our cohort differs from the Italian study in that secondary investigations were not limited to a single centre, the overall trend is similar. The higher rate of cardiac MRI in our study can be explained by the increasing availability and application of this test compared to the Italian study in 2004 (4).

Compared to the 2010 ESC recommendations adapted for less conservative limits for abnormal QT intervals, application of more contemporary ECG interpretation guidelines would reduce the number of athletes requiring further investigation following screening by up to 50% which would significantly impact health resources (Table 2). Specifically, the refined criteria would have resulted in 50% reduction in the number of echocardiograms, 12% reduction in the number of exercise tests, 8% reduction in Holter monitors, and 18% reduction in the number of cardiac MRI scans that would need to be performed to confirm (or refute) the diagnosis of cardiac disease.

Cost Analysis

Our study was intended to report the impact on the type and cost of further investigations following the modification of ECG criteria rather than assess the cost-effectiveness of cardiac screening. Our findings are comparable with a significantly smaller Swiss study of just over 1000 athletes who were also screened with ECG that was interpreted on the basis of the 2010 ESC recommendations with several modifications similar to the Seattle criteria (19). The study reported a cost of $146 per athlete screened and $39,119 per serious condition detected. Unlike our study, all athletes self-referred and were exclusively white. Furthermore, the indications for

additional investigations were consensually established by only two cardiologists, which does not reflect real-life practice. Another study from Qatar also reported the costs relating to ECG screening in 1,628 athletes also using recommendations resembling the Seattle criteria (20). The cost per athlete was significantly higher than our study and equated to $265. Besides a significantly smaller sample size, the study was not comparable to ours in several aspects. Over 50% of athletes were of Arabic origin which is not representative of athletes in the Western world. All investigations were conducted in a single centre and therefore not representative of nationwide screening of young athletes.

Compared to the 2010 ESC recommendations, the modifications in the Seattle and refined criteria equate to a cost advantage and would reduce the overall cost of screening by 16% and 21% per athlete respectively. Based on our sensitivity analysis, these savings may allow organisations to afford the additional costs of non-invasive risk stratification tests at time of diagnosis, gene testing and radiofrequency ablation for the Wolff-Parkinson-White syndrome ECG pattern.   Although the refined criteria were associated with a reduction in the number of abnormal ECGs compared to the Seattle criteria, this advantage did not translate to a significant cost saving. The discrepancy can be attributed to the differences in the interpretation of anterior T-wave inversion between the two criteria (2,7).T-wave inversion in the right precordial leads is associated with arrhythmogenic right ventricular cardiomyopathy, which invariably requires a plethora of cardiac investigations including cardiac MRI, signal averaged ECG, Holter monitor and exercise stress test for diagnosis (21). In white athletes, the refined criteria recommend investigation in athletes with anterior T-wave inversion beyond V1 whereas the Seattle criteria recommend further investigation only if T-wave inversion extends beyond V2 (Table 1). The added costs

associated with investigating a greater proportion of athletes with anterior T-wave inversion negate the positive impact of a lower number of abnormal ECGs with the refined criteria.

The 2010 ESC recommendations resulted in the detection of a higher number of minor congenital abnormalities compared with contemporary criteria but we believe this was fortuitous. Although left atrial enlargement or left axis deviation was present on the ECG in a significant proportion of such athletes, we have previously demonstrated that there is no difference in the prevalence of minor congenital cardiac abnormalities in athletes and healthy controls with either of these ECG anomalies compared to athletes with normal ECGs (22). Even after allowance for these diagnoses, the cost of screening remained lower with contemporary criteria.

Cost Issues and Clinical Implications to the Larger UK Athlete Population

Based on the Active People Survey, a national survey of sports participation, 3,245,400 young people (14-35 years) participated in competitive sport in 2014/15 (23). Extrapolation of our costs to these athletes means that a de novo screening programme for all athletes in the UK would cost $356,994,000 and detect a substantial number (9,736 athletes) harbouring conditions that are associated with exercise-related sudden cardiac death using the 2010 ESC recommendations (adapted for less conservative criteria for abnormal QT intervals). Application of the Seattle and refined criteria would cost $298,576,800 and $282,349,800 respectively, equating to a huge saving of approximately $58 to 75 million. These estimates do not take into consideration for the invariable cost reduction of screening the same cohort during subsequent years.

Whether these costs provide a feasible solution for all athletes is debatable. Application of the most specific ECG interpretation criteria (refined criteria) would translate to a cost of nearly $29,000 per diagnosis of a potentially serious cardiac condition and may be acceptable for lucrative organisations. However, considering the large number of exercising young individuals and the low incidence of exercise-related sudden cardiac death, it is arguable that the cost of nationwide screening may be excessive for less financially endowed sporting organisations, and could be invested in improving training and facilities for cardiopulmonary resuscitation (24,25,26).

Study Limitations

The cost analysis was based on subsidized amounts for preliminary assessment ($53 per athlete) and relatively modest costs of secondary investigations in the UK National Health Service which may be considerably cheaper compared to other healthcare models. Nevertheless, the systematic methodology of investigating a large number of athletes by experts in sports cardiology should enable a relatively precise estimate of the number of additional investigations required to other Western populations. Secondary investigations were at the discretion of the attending cardiologist and may have been influenced by personal clinical practice as would be expected in real-life clinical situations. It is prudent to emphasise that these costs relate solely to the detection of new cardiac conditions and do not account for any downstream costs of management and on-going clinical surveillance of affected athletes.

Finally, data relating to secondary investigations in athletes with abnormal history, physical examination or ECG relied solely on information provided by club doctors and may be subject to recall bias.

CONCLUSIONS

Contemporary ECG interpretation guidelines are associated with a cost reduction of up to 21% without compromising sensitivity to detect serious cardiac disease. These results represent a welcome saving for sporting organisations equipped with the infrastructure and expertise for cardiac screening in athletes.

CLINICAL PERSPECTIVES

Competency in Medical Knowledge

Modification of ECG interpretation guidelines improves specificity for detecting serious cardiac disease and is associated with a 21% reduction in the cost of cardiovascular screening in young athletes.

Translational Outlook

Sequential long term follow-up of young athletes is required to evaluate the impact of ECG modification on the cost effectiveness of screening with ECG.

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Figure Legends

Figure 1:

Title: ECG abnormalities with reference to the 2010 ESC recommendations, Seattle criteria and refined criteria.

Caption: Differences in criteria for an abnormal QT interval and abnormal T-wave inversion are responsible for the lower number of abnormal ECGs with the Seattle criteria and refined criteria compared to the 2010 ESC recommendations.

Central illustration:

Title: The financial impact of modification of ECG interpretation criteria in young athletes.

Key: ǂ adapted for less conservative criteria for an abnormal QT interval

Caption: Compared to the 2010 ESC recommendations, the costs for subsequent investigation following an abnormal ECG with the Seattle criteria and refined criteria are reduced by 21%.

Figure 2:

Title: Sensitivity analysis reporting the impact of several variables on the cost per athlete screened with the refined criteria.

Key: HCM=hypertrophic cardiomyopathy, EPS=electrophysiological study, LQTS=long QT syndrome, WPW= Wolff-Parkinson-White syndrome

Caption: Risk stratification tests at diagnosis, genetic testing and electrophysiological studies ± ablation for Wolff-Parkinson-White ECG pattern raise costs by $5 per athlete screened. Conversely, inclusion of previously screened athletes in the analysis reduces the cost per by $3 per athlete screened.

Tables

Table 1: Definition of ECG abnormalities in athletes according to the 2010 ESC

Recommendations (3), Seattle criteria (2) and refined criteria (7).

All 3 criteria	ST segment depression Pathological Q-waves Complete left bundle branch block Wolff-Parkinson-White syndrome pattern Brugada-like early repolarisation pattern Premature ventricular contractions Atrial or ventricular arrhythmia
2010 ESC recommendations	T-wave inversion Long QT interval >440 msec (male) or >460 msec (female) Short QT interval <380 msec Right ventricular hypertrophy Right or left axis deviation Right or left atrial enlargement Complete right bundle branch block Non-specific intraventricular delay (QRS >120 msec)
Seattle criteria	T-wave inversion beyond V2 in white athletes T-wave inversion beyond V4 in black athletes Long QT interval ≥470 msec (male) or ≥480 msec (female) Short QT interval ≤320 msec Right ventricular hypertrophy (in presence of right axis deviation) Left axis deviation Right or left atrial enlargement Non-specific intraventricular delay (QRS ≥140 msec)
Refined criteria	T-wave inversion beyond V1 in white athletes T-wave inversion beyond V4 in black athletes Long QT interval ≥470 msec (male) or ≥480 msec (female) Short QT interval ≤320 msec Complete right bundle branch block Non-specific intraventricular delay (QRS >120 msec) *Borderline variants (requiring investigation if >1 present)* T-wave inversion up to V4 in black athletes Right ventricular hypertrophy Left axis deviation Right axis deviation Right atrial enlargement Left atrial enlargement

Table 2: Cost and frequency of additional investigations following abnormality in history and physical examination, or ECG.

	Cost ($)	History and physical examination N (%)	ECG interpreted with 2010 ESC recommendations N (%)	ECG interpreted with Seattle criteria N (%)	ECG interpreted with refined criteria N (%)
Hospital appointment for further evaluation and additional investigations	249	79 (1.6%)	502 (10.2%)	295 (6.0%)	210 (4.3%)
Transthoracic echocardiography	112	66 (1.3%)	484 (9.8%)	274 (5.6%)	197 (4.0%)
Exercise stress test	258	12 (0.2%)	73 (1.5%) ‡ 10 (0.2%) †	58 (1.2%) ‡ 10 (0.2%) †	63 (1.3%) ‡ 10 (0.2%) †
24 hour ECG (Holter)	258	12 (0.2%)	47 (1.0%) ‡ 8 (0.2%) †	38 (0.8%) ‡ 8 (0.2%) †	42 (0.9%) ‡ 8 (0.2%) †
Cardiac magnetic resonance imaging (MRI)	319	1 (0.02%)	60 (1.1%)	45 (0.9%)	49 (1.0%)
24 hour blood pressure monitoring	258	4 (0.08%)	1 (0.02%)	1 (0.02%)	1 (0.02%)
Signal average ECG	40	0	4 (0.08%)	2 (0.04%)	4 (0.08%)
Electrophysiological study (± ablation)	3026	1 (0.02%)	3 (0.06%) ‡ 4 (0.08%) *	3 (0.06%) ‡ 4 (0.08%) *	3 (0.06%) ‡ 4 (0.08%) *
Cardiac computed tomography	167	1 (0.02%)	0	0	0
Transoesophageal echocardiography	438	0	1 (0.02%)	1 (0.02%)	1 (0.02%)
Provocation testing for Brugada syndrome	608	3 (0.06%)	0	0	0
Genetic testing for long QT syndrome and hypertrophic cardiomyopathy	912	0	9 (0.2%)	9 (0.2%)	9 (0.2%)

Key: ‡ diagnostic indication, †non-invasive risk stratification indication, * risk stratification and treatment for Wolff-Parkinson-White syndrome ECG pattern

Table 3: Characteristics of athletes diagnosed with disease implicated in sudden cardiac death

Pathology	Age/Gender	Ethnicity	Sport	H+P abnormality	ECG abnormality	Diagnostics	Risk stratification	Other	Outcome
HCM	34/Male	Caucasian	Ballet	Nil	Lateral TWI	ECHO, MRI	EST, Holter	Gene test	Retired
HCM	35/Male	Caucasian	Soccer	Nil	Inferior-lateral TWI	ECHO, MRI	EST	Gene test	Retired
HCM	33/Male	Caucasian	Rugby	Nil	Lateral TWI	ECHO, MRI	EST	Gene test	Retired
HCM	24/Male	Caucasian	Rugby	Nil	Inferior-Lateral TWI	ECHO, MRI	EST	Gene test	Playing against medical advice
HCM	19 /Male	Afro-Caribbean	Cricket	Nil	Inferior-Lateral TWI	ECHO, MRI	-	Gene test	Playing against medical advice
HCM	14/Male	Caucasian	Swimming	Nil	Inferior-Lateral TWI	ECHO, MRI	EST	Gene test	Playing against medical advice
LQTS	16/Female	Caucasian	Netball	Nil	QTc 480msec T-wave notching	ECHO, EST	Holter	Gene test	Playing against medical advice

LQTS	15/Male	Caucasian	Swimming	Nil	QTc 510msec T-wave notching	ECHO, EST	Holter	Gene test	Retired
LQTS	27/Male	Afro-Caribbean	Soccer	Nil	QTc 550msec T-wave notching	ECHO, EST	Holter	Gene test	Playing against medical advice
WPW ECG pattern	14/Female	Caucasian	Swimming	Nil	Short PR interval Delta wave	-	-	-	Conservative management
WPW ECG pattern	15/Male	Afro-Caribbean	Soccer	Nil	Short PR interval Delta wave	-	EST, Holter, EPS	-	Treated with radiofrequency ablation
WPW ECG pattern	16/Male	Caucasian	Rugby	Nil	Short PR interval Delta wave	-	EST, Holter. EPS	-	Treated with radiofrequency ablation
WPW ECG pattern	17/Female	Afro-Caribbean	Cricket	Nil	Short PR interval Delta wave	-	EST	-	Conservative management
WPW ECG pattern	17/Male	Caucasian	Rugby	Nil	Short PR interval Delta wave Inferior TWI	ECHO	EST, Holter, EPS	-	Treated with radiofrequency ablation
WPW ECG pattern	20/Male	Caucasian	Rugby	Nil	Short PR interval Delta wave	-	EST, Holter, EPS	-	Treated with radiofrequency ablation

Key: ECHO= echocardiogram, EST=exercise stress test, EPS= electrophysiology study, H+P=history and physical examination, HCM=hypertrophic cardiomyopathy, LQTS=long QT syndrome, MRI=magnetic resonance imaging, msec= milliseconds, QTc= QT interval corrected for heart rate, TWI=T-wave inversion, WPW= Wolff-Parkinson-White syndrome