Sarah Koch | Michael Cassel | Karsten Linne | Frank Mayer
Juergen Scharhag

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# ECG and echocardiographic findings in 10–15-year-old elite athletes

**Sarah Koch[1,2], Michael Cassel[1], Karsten Linné[1], Frank Mayer[1] and Jürgen Scharhag[1,3]**

**Abstract**

**Background:** Data on electrocardiographic and echocardiographic pre-participation screening findings in paediatric athletes are limited.

**Methods and results:** 10–15 year-old athletes ($n = 343$) were screened using electro- and echocardiography. The electrocardiogram (ECG) was normal in 220 (64%), mildly abnormal in 108 (31%), and distinctly abnormal in 15 (4%) athletes. Echocardiographic upper reference limits (URL, 97.5 percentile) for the left ventricular (LV) wall thickness in 10–11-year-old boys and girls were 9–10 mm and 8–9 mm, respectively; in 12–13-year-old boys and girls 9–10 mm; and in 14–15-year-old boys and girls 10–11 mm and 9–10 mm, respectively. Three athletes were excluded from competitive sports: one for symptomatic Wolff-Parkinson-White syndrome with a normal echocardiogram; one for negative T-waves in $V_1$–$V_4$ and a dilated right ventricle by echocardiography suggestive of (arrhythmogenic) right ventricular disease; and one for normal ECG and biscupid aortic valve including an aneurysm of the ascending aorta detected by echocardiography. Related to echocardiographic findings, the sensitivity and specificity of the ECG to identify cardiovascular abnormalities was 38% and 64%, respectively. The ECG's positive-predictive and negative-predictive values were 13% and 88%, respectively. The numbers needed to screen and calculated costs were 172 for ECG (€7049), 172 for echocardiography (€11,530), and 114 combining ECG and echocardiography (€9323).

**Conclusions:** Compared to adults, paediatric athletes presented with fewer distinctly abnormal ECGs, and there was no gender difference in paediatric athletes' ECG-pattern distribution. A combination of ECG and echocardiography for pre-participation screening of paediatric athletes is superior to ECG alone but 30% more costly.

**Keywords**

ECG, echocardiography, paediatric athlete, pre-participation screening, sudden cardiac death

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## Introduction

Major sporting and medical associations (American Heart Association, AHA[1], European Society of Cardiology, ESC[2], and International Olympic Committee, IOC[3]) support cardiovascular screenings of adult athletes for the timely detection of cardiovascular abnormalities predisposing to sudden cardiovascular death (SCD).[1–3] The annual incidence of SCD in children and adolescents lies between 0.6–6.2 per 100,000 person-years.[4,5] Paediatric athletes participate in competitive sports at levels up to Youth World Championships and Youth Olympic Games; therefore, there are many questions regarding the adequacy of pre-participation screening protocols and their applicability to paediatric athletes.[6,7] Age, gender, and inter-individual differences in onset and progression of maturation must be considered when assessing cardiovascular adaptations to intensive physical training. Resting ECG patterns of paediatric athletes may already show physiological cardiac adaptations to chronic training resembling pathological abnormalities associated with occult heart diseases predisposing for SCD.[6–8] Echocardiography is another technique that

[1]University of Potsdam, Potsdam, Germany
[2]University of British Columbia, Vancouver, Canada
[3]University of Heidelberg, Heidelberg, Germany

**Corresponding author:**
Jürgen Scharhag, Internal Medicine III: Cardiology, Angiology and Pneumology, Im Neuenheimer Feld 410, 69120 Heidelberg, Germany.
Email: juergen.scharhag@med.uni-heidelberg.de

can be used to differentiate between cardiac abnormalities and physiological adaptations to intensive training in athletes.[1–3]

An ongoing controversy has been the inclusion of a resting electrocardiogram (ECG) to the screening guidelines of athletes.[8] The AHA limits its initial screening recommendations to a medical history and physical examination due to concerns regarding false-positive findings, cost-effectiveness, and limited resources.[1] The ESC and IOC include a resting ECG in their cardiovascular screening recommendations based on Italian studies.[4,9,10] After the implementation of mandatory screenings in all competitive athletes aged between 12 and 35 years in Italy, the annual incidence of SCD in athletes decreased by 89% (from 3.6/100,000 person-years in 1979/80 to 0.4/100,000 person-years in 2003/04).[4] Steinvil et al.[11] did not find a decrease in the SCD rate in their retrospective analysis and pointed out that the decrease in the annual incidence of SCD reported by Corrado et al.[4] may be influenced by large year-to-year variations of SCD rates in athletes.

Data comparing ECG and echocardiographic findings of pre-participation screenings in paediatric athletes are unavailable. The purpose of this study was to compare ECG and echocardiographic findings in 10–15-year-old competitive athletes. Additionally, we aimed to derive age- and sex-specific echocardiographic upper reference limits (URLs) for this group of athletes.

## Methods

### Study population

Between October 2008 and February 2009, 343 athletes (189 males, 154 females; aged 10–15 years) were screened at the Centre for Sports Medicine at the University of Potsdam, which is responsible for the pre-participation screening of athletes transferring to elite sport schools in the federal state of Brandenburg, Germany. All athletes underwent a medical history, physical examination, 12-lead ECG at rest, and two-dimensional echocardiography. The study was approved by the institutional review board of the University of Potsdam. All parents gave their written informed consent.

Athletes engaged in 28 sport disciplines and were assigned into groups according to sex and age. We differentiated between 10–11-year-olds ($n = 116$), 12–13-year-olds ($n = 191$), and 14–15-year-olds ($n = 36$). The anthropometric data are summarized in Table 1.

### Electrocardiography

A 12-lead resting ECG (Cardisuny Alpha 600ax; Fukuda ME Kogoyo, Tokyo, Japan) was recorded at 50 mm/s in supine position. Manually interpreted ECGs were assigned into three subgroups previously defined for adult athletes by Pelliccia et al.[9]

*Normal ECG or ECG with minor alterations.* The ECGs were classified as normal or with minor alterations when one or more of the following alterations were present: increased PR interval duration (>0.20 s); mild increase in R- or S-wave voltage (25–29 mm); early repolarization (ST elevation ≥2 mm in >2 leads; incomplete right bundle branch block (RSR pattern in V1 and V2 of <0.12 s in duration); and sinus bradycardia (<60 bpm).

*Mildly abnormal ECG.* ECGs were classified as 'mildly abnormal' if they included patterns possibly indicating a cardiovascular disease: increased R- or S-wave voltage (30–34 mm); Q-waves 2–3 mm in depth and present in ≥2 leads; repolarization patterns with either flat, minimally inverted or particularly tall (i.e. ≥15 mm) T-waves in ≥2 leads; abnormal R-wave progression in the anterior precordial leads; right bundle branch block (RST pattern ≥0.12 s in V1 and V2); right atrial enlargement (peaked P-waves ≥2.5 mm in leads II, III or V1); left atrial enlargement (prolonged positive P-wave in lead II and/or deep, prolonged negative P-wave in V1); and short PR interval (≤0.12 s).

*Distinctly abnormal ECG.* Distinctly abnormal ECGs included patterns that were strongly indicative of cardiovascular disease: striking increase in R- or S-wave voltage (≥35 mm) in any lead; Q-waves ≥4 mm in depth and present in ≥2 leads; repolarization pattern with inverted T-wave >2 mm in ≥2 leads; left bundle branch block; marked left (≤−30°) or right (≥110°) QRS axis deviation; and Wolff-Parkinson-White (WPW) pattern.

### Echocardiography

Two-dimensional M-mode and Doppler echocardiography was performed (Xario SSA-660A; Toshiba Medical Systems Corporation, Otawara, Japan) with a 3.0 MHz transducer (PST-30BT; Toshiba). All subjects were examined in left lateral decubitus position by the same experienced echocardiographer. In accordance with the American Society of Echocardiography guidelines, images were obtained in the standard parasternal long and short axis and in the apical four-chamber view.[12] The following parameters were obtained in the M-mode of the parasternal long axis view: left and right ventricular end-diastolic diameter (LV EDD and RV EDD, respectively); interventricular septal wall thickness (IVS); posterior wall thickness (PW); end-diastolic diameter of the aortic root; and end-diastolic left atrial diameter. The LV diastolic function was assessed

**Table 1.** Anthropometric data of 10–15-year-old athletes.

| Age group (years) | Sex | *n* | % | Height (cm) | Weight (kg) | BMI (kg/m$^2$) | BSA (m$^2$) | Years of training | Hours of training (h/week) |
|---|---|---|---|---|---|---|---|---|---|
| 10–11 | MF | 116 | 34 | 156 ± 9 | 44 ± 8 | 18.0 ± 1.9 | 1.4 ± 0.2 | 4.6 ± 2.0 | 5.9 ± 2.9 |
| | M | 58 | | 155 ± 9 | 44 ± 8 | 18.1 ± 1.9 | 1.4 ± 0.2 | 5.3 ± 2.0 | 6.0 ± 3.2 |
| | F | 58 | | 157 ± 9 | 45 ± 8 | 18.0 ± 2.0 | 1.4 ± 1.6 | 4.0 ± 1.8 | 5.7 ± 2.6 |
| 12–13 | MF | 191 | 56 | 160 ± 9 | 49 ± 10 | 19.1 ± 2.6 | 1.5 ± 0.2 | 4.7 ± 2.3 | 5.7 ± 2.8 |
| | M | 116 | | 160 ± 10 | 49 ± 11 | 19.1 ± 2.8 | 1.5 ± 0.2 | 4.8 ± 2.3 | 5.8 ± 2.8 |
| | F | 75 | | 159 ± 8 | 49 ± 9 | 19.1 ± 2.6 | 1.5 ± 0.2 | 4.6 ± 2.2 | 5.6 ± 2.8 |
| 14–15 | MF | 36 | 20 | 165 ± 9 | 58 ± 10 | 21.0 ± 2.3 | 1.6 ± 0.2 | 5.9 ± 3.4 | 13.7 ± 6.7 |
| | M | 15 | | 166 ± 12 | 60 ± 14 | 21.4 ± 2.7 | 1.6 ± 0.2 | 4.8 ± 2.6 | 11.3 ± 8.1 |
| | F | 21 | | 165 ± 7 | 56 ± 7 | 20.8 ± 2.0 | 1.6 ± 0.1 | 6.6 ± 3.8 | 14.8 ± 5.2 |

Values are mean ± standard deviation; BMI, body mass index; BSA, body surface area; MF, males and females combined; M, males; F, females.

in the apical four-chamber view by pulsed wave Doppler of the LV inflow at the tips of the mitral valve leaflets. Valve functions were evaluated with coloured and continuous Doppler. Relative wall thickness was calculated and LV EDD was indexed to body surface area.[13]

### *Number needed to screen and cost calculations*

The number needed to screen (NNS) to diagnose one athlete with a cardiovascular finding that requires exclusion from competitive sports was determined for three screening protocols. All three protocols included the athlete's health history and a physical examination in addition to either a resting ECG or echocardiography or a combination of both. Based on the NNS for each protocol, the resulting costs were calculated based on Germany's cost recommendations for medical services in 2010.[14] The recommended costs were as follows: health history and physical examination, €26.23 (~US$37); 12-lead resting ECG, €14.75 (~US$21), and echocardiogram, €40.80 (~US$58).[14]

### *Statistical analysis*

Data are expressed as means and standard deviations (SD). The unpaired t-test was run to assess differences between means, and the $\chi^2$-test was used to evaluate differences between proportions. An alpha error <0.05 was considered statistically significant. Differences between the three ECG subgroups were assessed by ANOVA. Echocardiographically determined URLs of cardiac dimensions were defined as the 97.5 percentile of our study population. The lower reference limit (LRL) for the E- to A-wave ratio (E/A) was defined as the 2.5 percentile. Cardiac dimensions were classified as 'increased' when they equalled or exceeded the calculated URL, indexed by sex and age of the according parameter. All analyses were performed using JMP 5.0.1. (SAS Institute, Cary, NC, USA).

## Results

### *ECG patterns and echocardiographic findings*

Of the 343 athletes, normal ECGs were recorded in 220 athletes (64%). Of those 220 athletes, 108 (28%) were completely normal and 112 (36%) presented with minor alterations. Abnormal ECGs were identified in 123 athletes (36%), which included 108 (32%) mildly abnormal ECGs and 15 (4%) distinctly abnormal ECGs. The prevalence of all ECG patterns is summarized in Table 2.

Abnormal echocardiographic findings were present in all ECG subgroups, but they were more common in those with normal ECGs. Of the 42 athletes with echocardiographic abnormalities, 24 (57%) athletes had a normal ECG, 15 (36%) had a mildly abnormal ECG, and three (7%) had a distinctly abnormal ECG. Of the 343 athletes, 24 athletes (7%) with a normal ECG were found to be false-negatives with respect to positive echocardiographic findings. Of the 301 athletes without evidence of echocardiographic abnormalities, 194 athletes had a normal ECG and 107 had an abnormal ECG. Of the 107 athletes with an abnormal ECG, 95 athletes presented with a mildly abnormal ECG and 15 had a distinctly abnormal ECG. The 15 athletes (4%) with distinctly abnormal ECGs were considered false-positives with respect to negative echocardiographic findings. The power of distinctly and mildly abnormal

**Table 2.** Distribution of ECG abnormalities in 10–15-year-old athletes.

| Normal ECG/minor alterations ($n = 220$) | | Mildly abnormal ECG ($n = 108$) | | Distinctly abnormal ECG ($n = 15$) | |
|---|---|---|---|---|---|
| R or S wave 25–29 mm | 18 (8) | R or S wave 30–34 mm | 2 (2) | R or S wave ≥35 mm | 3 (20) |
| ST segment elevation | 10 (5) | Flat/tall T wave | 24 (22) | T wave inversion | 3 (20) |
| Incomplete RBBB | 45 (20) | Q wave 2–3 mm | 3 (3) | Q wave ≥4 mm | 0 (0) |
| PR interval >0.20 s | 1 (0.5) | Incomplete R wave progression $V_1$ to $V_3$ | 1 (1) | 30° ≤QRS axis ≥110° LAD/RAD | 9 (60) 3/6 |
| Sinus bradycardia <60 bpm | 48 (22) | PQ interval ≤0.12 s | 89 (82) | LBBB | 0 (0) |
| | | RBBB | 2 (2) | WPW | 1 (7) |

Values are *n* (%); Incomplete RBB, incomplete right bundle branch block; RBBB, right bundle branch block; LAD, left axis deviation; RAD, right axis deviation; WPW, Wolff-Parkinson-White syndrome.

ECGs for identifying cardiovascular abnormalities observed with echocardiography was as follows: sensitivity 43%, specificity 64%, positive-predictive accuracy 11%, negative-predictive accuracy 89%.

In the 42 athletes (12%) with echocardiographic findings classified as relevant or abnormal, the following were found: 14 cases of increased LV EDD (LV EDD relative to body height ≥32–33 mm/m); 36 increased LV wall-thickness (increased IVS for girls ≥8.8–10 mm; increased IVS for boys ≥10.0–11.5 mm; increased PW for girls ≥8.5–9.0 mm; increased PW for boys ≥8.9–11.0 mm); five bicuspid aortic valves (two anatomic bicuspid aortic valves, three functional bicuspid aortic valves). Three athletes with a bicuspid aortic valve also presented with an increased LV wall thickness. Further findings included: one atrial septal aneurysms, one borderline dilated left atrium (≥37 mm), and one borderline dilated right ventricle (≥27 mm).

## *ECG patterns in relation to age and sex*

There were no gender or age differences in the prevalence of ECG patterns. Normal ECGs were recorded in 116 boys (62%) and 104 girls (67%). Mild ECG abnormalities were found in 65 boys (35 %) and 43 girls (28%), and distinctly abnormal ECGs were assessed in seven boys (4%) and eight girls (5%).

## *Cardiac dimensions and upper reference limits*

Cardiac dimensions for 10–15-year-old athletes are presented in Table 3. The URL for LV wall thickness in 10–11-year-old boys and girls were 9–10 mm and 8–9 mm, respectively. In 12–13-year-old boys and girls the URL for the LV EDD was 9–10 mm, and in 14–15-year-old boys and girls 10–11 mm and 9–10 mm, respectively.

## *Relevant ECG and echocardiographic findings*

A 12-year-old boxer with a normal echocardiogram was diagnosed with WPW syndrome based on his ECG. He was temporarily excluded from competitive sports but cleared following successful ablation. An 11-year-old soccer player and a 12-year-old judoka were diagnosed with a complete right bundle branch block. Two athletes presented with a borderline short PR interval, suggestive of Lown-Ganogn-Levine syndrome.

The ECGs of an 11-year-old marksman and a 13-year-old handball player showed negative T-waves in V1–V4 suggestive of cardiomyopathy. Although the marksman presented with a normal echocardiogram, cardiac magnetic resonance imaging (CMR) was performed to exclude myocarditis. Due to a negative CMR, he was eligible for competitive sports. The handball player with negative T-waves in V1–V4 also presented with a dilated RV and right atrium in his echocardiogram, which was confirmed by CMR and indicative for arrhythmogenic right ventricular cardiomyopathy. A third CMR was performed in a 13-year-old boxer with a normal ECG and a bicuspid aortic valve and aneurysm of the ascending aorta by echocardiography. Both, the boxer and the handball player were excluded from competitive sports.

Annual echocardiography follow ups were recommended for 13 athletes with increased LV EDDs based on their age and body dimensions ($n = 5$), bicuspid aortic valves ($n = 5$), atrial septal aneurysms ($n = 2$), and a borderline increased right atrium ($n = 1$).

No athletes were excluded from competitive sports solely based on the results of the medical examination including blood pressure measurements.

**Table 3.** Cardiac dimensions (m ± sd) and upper reference limits (URL) in 10–15-year-old athletes.

| Gender and age group (years) | *n* | LV EDD (mm) | | LV EDD/BSA (mm/m²) | | IVS (mm) | | PW (mm) | | RWT (%) | | E (m/s) | | A (m/s) | | E/A | | LAD (mm) | | Ao (mm) | | RV EDD (mm) | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | m ± sd | URL | m ± sd | URL | m ± sd | URL | m ± sd | URL | m ± sd | URL | m ± sd | URL | m ± sd | URL | m ± sd | LRL | m ± sd | URL | m ± sd | URL | m ± sd | URL |
| Boys 10–11 | 58 | 45 ± 4 | 53 | 33 ± 3 | 39 | 7.7 ± 1.0 | 10.3 | 6.8 ± 1.2 | 8.9 | 32 ± 4 | 42 | 97 ± 12 | 131 | 49 ± 7 | 63 | 2.0 ± 0.3 | 1.5 | 30 ± 4 | 37 | 24 ± 2 | 28 | 20 ± 3 | 29 |
| Girls 10–11 | 58 | 45 ± 3 | 54 | 32 ± 3 | 40 | 7.3 ± 0.9 | 8.8 | 6.7 ± 0.8 | 8.5 | 31 ± 4 | 40 | 95 ± 13 | 122 | 51 ± 9 | 73 | 1.9 ± 0.4 | 1.3 | 29 ± 3 | 36 | 23 ± 2 | 29 | 17 ± 3 | 26 |
| Boys 12–13 | 116 | 47 ± 4 | 55 | 31 ± 3 | 38 | 8.1 ± 0.9 | 10.0 | 7.4 ± 1.0 | 10.0 | 32 ± 4 | 42 | 97 ± 12 | 121 | 51 ± 11 | 71 | 2.0 ± 0.4 | 1.1 | 31 ± 3 | 37 | 24 ± 3 | 29 | 19 ± 4 | 27 |
| Girls 12–13 | 75 | 46 ± 3 | 53 | 32 ± 3 | 38 | 7.6 ± 9.6 | 9.6 | 7.0 ± 0.9 | 9.0 | 32 ± 4 | 40 | 95 ± 10 | 118 | 52 ± 9 | 72 | 1.9 ± 0.4 | 1.3 | 29 ± 5 | 36 | 23 ± 2 | 28 | 18 ± 4 | 27 |
| Boys 14–15 | 15 | 48 ± 4 | 55 | 29 ± 3 | 33 | 8.8 ± 1.3 | 11.5 | 8.1 ± 1.5 | 11.0 | 32 ± 5 | 42 | 93 ± 11 | 117 | 49 ± 10 | 70 | 2.0 ± 0.4 | 1.2 | 33 ± 4 | 39 | 26 ± 2 | 29 | 20 ± 5 | 27 |
| Girls 14–15 | 21 | 47 ± 3 | 54 | 30 ± 2 | 33 | 8.4 ± 1.0 | 10.0 | 7.6 ± 1.1 | 9.0 | 34 ± 4 | 39 | 94 ± 8 | 103 | 47 ± 7 | 63 | 2.0 ± 0.3 | 1.5 | 30 ± 3 | 37 | 25 ± 2 | 29 | 19 ± 4 | 25 |

Echocardiographically determined cardiac dimensions are presented as mean ± standard deviation; URL, upper reference limit; LRL, lower reference limit; LV EDD, left ventricular end-diastolic diameter; BSA, body surface area; IVS, interventricular septum; PW, posterior wall thickness; RWT, relative wall thickness; E, E-wave; A, A-wave; LAD, left atrial diameter; Ao, aortic root diameter; RV EDD, right ventricular end-diastolic diameter.

### *Number needed to screen and cost calculations*

The NNS was 172 for ECG (two athletes were excluded: one for WPW; one for negative T-waves in leads V1–V4), 172 for echocardiography (two athletes were excluded: one for RV dilatation; one for bicuspid aortic valve with aneurysm of the ascending aorta), and 114 for the combination of ECG and echocardiography (one for WPW; one for negative T-waves in leads V1–V4 due to RV dilatation; one for bicuspid aortic valve with aneurysm of the ascending aorta). Based on the NNS and the screening protocol the calculated costs to detect one paediatric athlete at risk for SCD were €7049 (~US$10,088) for a resting ECG only, €11,530 (~US$16,507) for echocardiography only, and €9323 (~US$13,351) for a protocol combining the ECG and echocardiography.

## Discussion

The present study compared ECG and echocardiographic findings in 10–15-year-old athletes. The prevalence of ECG abnormalities in paediatric athletes was similar to adult athletes, but no gender differences were found.[9] Related to echocardiographic findings the ECG in paediatric athletes showed a high negative-predictive value that is comparable to adult athletes.[9] Additional echocardiography detected relevant echocardiographic abnormalities that were not detected by ECG alone and could also exclude cardiac abnormalities suspected by ECG.

### *ECG findings*

The distributions of ECG patterns found in 10–15-year-old athletes were different to those reported in adult athletes.[9] Abnormal ECGs were found in 36 (10%) paediatric athletes as opposed to 40% in adult athletes.[9] Also the prevalence of the mildly abnormal and distinctly abnormal ECGs differed between paediatric and adult athletes. Increased Q-, R-, and S-waves ranged between 19–36% in adult athletes[9] and between 3–8% in our paediatric athletes. Differences in the distribution of ECG patterns between paediatric and adult athletes can be caused by: shorter periods of systematic training including high training volumes and intensities resulting in cardiovascular adaptations; higher percentages of body fat in paediatric athletes, which could influence the amplitude of ECG waves,[15,16] low levels of sex-hormones, and the absence of gender differences in the levels of sex hormones.

### Echocardiographic findings

The cardiac dimensions determined in 10–15-year-old elite athletes confirmed previous data for athletes of similar age.[17–19] Sharma et al.[17] investigated the physiological limits of LV hypertrophy in 720 British elite athletes, aged 14–16 years. Left ventricular dimensions measured in British male athletes (IVS 9.5 mm; PW 9.5 mm, LV EDD 51.6 mm)[17] were slightly greater than in 14–15-year-old boys of our study. There were no differences in IVS and LV EDD between the British girls and the 14–15-year-old girls from this study, although PW (8.6 mm) in the British girls was slightly greater. Differences in the competition level might have been responsible for these findings as 50% of the screened British athletes competed on a national level.

When comparing our data for 12–13-year-old boys to Serbian athletes of same age, similar values can be found for LV EDD (46.6 mm) and IVS (8.5 mm).[18] Differences in training volume (Serbian athletes trained 9 h per week on average) and measurement techniques might be responsible for a greater mean in PW (8.2 mm) in Serbian athletes.[18]

### Comparison of ECG and echocardiographic findings

Structural cardiovascular diseases were rarely responsible for abnormal ECG patterns in 10–15-year-old athletes. Of the 42 paediatric athletes with cardiovascular abnormalities, 18 presented with a mildly or distinctly abnormal ECG pattern. ECG abnormalities in paediatric athletes may not directly represent structural cardiac adaptations to chronic systematic training, as there were no statistically significant differences in the cardiac dimensions between the three ECG subgroups.

False-negative ECGs have been a concern in regards to the inclusion of the resting ECG to a standardized pre-participation protocol as they mandate costly investigations or false disqualifications of athletes.[1,2,8,9,20,21] With 4% false-positive ECGs compared to echocardiography, our findings were in accordance with other studies, reporting false-positive results between 1.9 and 11%.[4,9,22] Hill et al.[20] showed that the ECG interpretation of paediatric athletes is challenging, even when performed by paediatric cardiologists. To decrease the rate of false-positive ECGs, and to uniform the evaluation of athletes' screenings, Heidbüchel et al.[23] proposed a curriculum for sports cardiologists, which includes age as an important factor in the interpretation of ECG patterns.

### Number needed to screen and cost calculations

Three out of 343 athletes were excluded from competitive sports (one for WPW, one for negative T-waves in leads V1–V4 combined with a dilated RV by echocardiography; one for bicuspid aortic valve with aortic aneurysm). Thus, the NNS was 172 with a protocol consisting of medical history, physical examination, and either resting ECG or echocardiography. The NNS for a protocol that combined ECG and echocardiography was 114. This NNS is comparable to 143 athletes needed to screen in a Dutch population of 12–35-year-old athletes.[22] Steinvil et al.[11] report a NNS of 33,000 among an Israeli athlete population, aged 12–44 years. This discrepancy may be due to their retrospective study design that analysed the NNS of athletes' screening examinations based on reported cases of SCD among Israeli athletes in two major newspapers in Israel, while our calculations are based on critical ECG and echocardiographic findings in a younger athlete population.

Even though the costs to detect one paediatric athlete at risk for SCD were lowest for ECG, one cardiovascular disease would have been missed if the ECG were the only screening technique. Thus, echocardiography can be a method to reduce false-negative ECG findings. Also, echocardiography has the potential to reduce the rate of false-positive ECGs. Further discussions are necessary to determine the necessity of echocardiography as a routine screening tool for elite athletes. Based on our experience, we recommend a screening protocol that combines annual resting ECGs and one echocardiographic screening prior to enrolment in elite sport schools in 10–15-year-old athletes. A protocol that combines the resting ECG and echocardiography is superior to ECG alone, but costs approximately 30% more. Ultimately, it is a philosophical question as to whether or not it is worth the money spent to save an athlete's life. This question needs to be addressed on an international, national and provincial/state level by politicians, sports associations, insurances, and lastly by the athlete.

### Limitations

This was a single-centre study, where all echocardiograms were performed and interpreted by a single experienced sonographer. The examiner, who interpreted the ECGs differed from the sonographer. Both were blinded to each other's findings until a mutual review was performed upon the completion of the entire test battery. Single-centre and single-observer studies carry the risk of observer bias and systematic error. For future studies, a multi-centre and multi-examiner design would be preferable. The present study was not of a longitudinal design, which is why no clinical end point could be taken into account. The ECG classification in this study follows the criteria used by Pelliccia et al.[9] to allow for comparisons between paediatric and adult athletes. In November 2009, shortly after the completion of data analysis, updated ECG classification criteria were published by Corrado et al.[24] Neither the criteria published by Corrado et al.[24] nor the criteria used by Pelliccia et al.[9] were specifically intended for paediatric athletes. This could be another reason for differences in ECG-pattern distribution between adult and paediatric elite athletes.

## Conclusion

The distribution of ECG patterns between 10–15-year-old athletes and adult athletes differ from each other. In contrast to adult athletes, no gender differences exist in the ECG patterns of paediatric athletes, which probably reflect absent differences in growth, induced by sex hormones at older ages. The resting ECG is helpful for pre-participation screening of paediatric athletes by its high negative-predictive value. Due to the low sensitivity and false-positive ECGs, echocardiography is an important technique to detect structural cardiac abnormalities in paediatric athletes. Echocardiographic URLs described in this study may be helpful to differentiate between physiological and pathological cardiac adaptations in children participating in competitive sports.

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### Conflict of interest

The authors have no conflict of interest.

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