ECG evaluation in 11 949 Italian teenagers: results of screening in secondary school

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Aim There is lack of evidence regarding the screening role of ECG for sudden cardiac death (SCD) prevention. Our aim was to evaluate the prevalence of ECG abnormalities among teenagers according to sport participation and competitive status.

Methods Eleven thousand nine hundred and forty-nine Italian pupils from 179 secondary schools (13–19 years) were consecutively enrolled. ECG abnormalities were divided into minor and major. Medical history, clinical examination and sport activity information were acquired. Further evaluations were suggested in case of major ECG abnormalities. Follow-up was performed at 2 years.

Results N = 1945 (16%) pupils had ECG abnormalities. Major ECG abnormalities were detected in 13% of the cohort, minor in 34%. ECG abnormalities were more common in nonathletes compared with athletes. A diagnosis of cardiac disease was reached in 25 (1.6%) of the pupils with major ECG abnormalities.

Conclusion ECG abnormalities are common among young populations and more prevalent in nonathletes. Among pupils with major ECG abnormalities 1.6% had a cardiac disease diagnosis. Our results are in line with the data supporting ECG screening in the general young population.

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Keywords: competitive athletes, ECG, noncompetitive athletes, screening, sudden cardiac death, teenagers

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Introduction Sudden cardiac death in the young (SCD-Ys) is a shocking event and represents an unresolved public health problem. The incidence of SCD-Ys ranges from 0.46 to 3.7 per 100 000 persons. Hypertrophic cardiomyopathy, arrhythmogenic right ventricular cardiomyopathy, coronary artery abnormalities, acute myocarditis and cardiac ion channelopathies represent the leading causes of SCD-Ys and are frequently under-detected before the occurrence of the fatal event. SCD often occurs without any previous warning symptoms.

A large body of evidence has demonstrated the usefulness of ECG in the early diagnosis of heart disease associated with SCD. Nevertheless, ECG screening programs for the general young population are still being debated. According to the European Society of Cardiology (ESC) and the International Olympic Committee, an ECG is recommended for the evaluation of young competitive athletes in order to prevent SCD, while routine ECG in young competitive athletes is not recommended by the American Heart Association.

Recently, the UK national screening program in the general young population found that the inclusion of an ECG increases the diagnostic yield for cardiac disease by five-fold and it is associated with a significant cost reduction.

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Maron et al. analyzed retrospectively the Minnesota registry observing that SCD was eight-fold more common in nonathletes than athletes. A comparison of the prevalence of ECG abnormalities between competitive athletes, non-competitive athletes and sedentary subjects is lacking.

The aim of the present study is to evaluate the prevalence of ECG abnormalities among an unselected population of Italian students (teenagers) and to evaluate the difference between nonathletes, competitive athletes, and noncompetitive athletes.

**Methods**

**Study population**

Sudden Cardiac Death Prevention Program in the young is a prospective observational registry funded by the ‘Italian Heart and Circulation Foundation’ and ‘Fondazione Roma’ created in order to screen Italian pupils by ECG. Over an interval time of 4 years, 11,949 Italian pupils from 179 secondary schools (lower and upper school, aged 13–19 years) among 10 different regions (Veneto, Abruzzo, Calabria, Campania, Lazio, Lombardia, Piemonte, Puglia, Sicilia, Toscana) were consecutively enrolled in the study and underwent ECG screening. There were no exclusion criteria. Informed consent was obtained by the student if at least 18 years old or by parents in the case of minors. The study was approved by the hospital Ethical Review Board at the Policlinico ‘Umberto I’, University Hospital of ‘Sapienza’ University of Rome, according to the Declaration of Helsinki.

**ECG acquisition and analysis**

Standard 12-lead ECGs were performed in the supine position using the handheld Mortara ELI-10 Mobile paperless electrocardiograph. ECG tracing was achieved at 25 mm/s paper speed and 10 mm/mV. Low pass filtering was set at 40 mHz.

Acquisition was performed in the schools by a group of 10 volunteer cardiologists in order to guarantee high-quality ECG trace and the possibility to evaluate the ECG immediately after the acquisition. A second ECG was acquired whether the first ECG showed one of the following conditions: PR interval greater than 200 ms, ECG was acquired after hyperventilation; abnormal T-wave inversion in leads V2–V4, ECG was repeated at 50 mm/s paper speed in order to detect epsilon waves; type III Brugada pattern in leads V1 or V2, ECG was repeated with leads V1 and V2 placed in the third or second intercostal space.

Each ECG was then transmitted to the ECG analysis center at Sapienza University of Rome, where two dedicated cardiologists evaluated all the ECGs defining them as ‘normal’ or ‘abnormal’, blinded to sport information. Furthermore, ECG abnormalities were divided into ‘minor’ and ‘major’ according to the definition reported in Table 1 and adapted from the latest recommendations for electrocardiographic interpretation in athletes. The classification of ECG findings was modified as the ECG analysis was carried out blinded to sport information and the same criteria were used for the whole population.

For the ECG analysis, all the following evaluations were performed manually with the use of the calipers: heart rate; QRS axis; P-wave, Q-wave, R-wave, S-wave, and T-wave voltages; ST-segments; QRS duration; PR interval and QT interval. The QT interval was measured by means of the tangent method and corrected for heart rate with Bazett’s formula.

In case a second ECG was acquired during the first level of analysis, the first ECG was marked in a dedicated box, in order to inform the ECG analysis center to analyze the second ECG.

Pupils who had major abnormal ECG findings had been informed and referred to the local cardiologist for further evaluation.

**Medical history and clinical examination**

The presence of risk factors, past medical history and sporting activity were investigated by a questionnaire.

Competitive athletes were considered ‘individuals who are involved in regular (usually intense) training in organized individual or team sports, with an emphasis on competition and performance’. They ‘span the age spectrum and can compete at the youth, high school, academy, university, semi-professional, professional, national, international, and Olympic levels’. Usually, they exercise more than 6 h/week.

Noncompetitive athletes were defined as individuals ‘engaged in sports for pleasure and leisure-time activity’. Nonathletes constituted sedentary individuals.

**Follow-up**

A follow-up at 12 and 24 months was performed by phone call in order to assess the incidence of overall death, cardiac death, resuscitated cardiac arrest or diagnosis of cardiac disease. For unavailable students, the schools were directly contacted in order to assess if any death had occurred in the period under investigation.

**Statistical analysis**

Baseline characteristics were reported as median and interquartile range (IQR) for continuous variables and frequencies and proportions for categorical variables. In order to examine the normality distribution of the data, Shapiro–Wilk test was used. For the ECG findings, prevalence estimates were calculated in all the subgroups of students considered in this study. Chi-square test with continuity correction was used to examine the association between categorical variables. Kruskal–Wallis test was used to compare numerical variables, as the outcome variable was not normally distributed. Post hoc analysis was performed to evaluate the differences among the three groups (competitive athletes, noncompetitive athletes and nonathlete populations).
Bonferroni’s correction was applied to correct for multiple testing. Multivariate multinomial logistic regression was performed to adjust odds ratios in an examination of the impact of sport on the presence of minor or major ECG abnormalities. Variables statistically significant at univariate analysis were selected. A significance level of 0.05 was used for all tests. All the analyses were performed using R version 3.6.2 (https://www.R-project.org/).

**Results**

**Baseline characteristics**

We enrolled 11,949 students, the mean age was 15.6 ± 3.5 years and 47.2% were boys. Baseline characteristics of the cohort are presented in Table 2.
characteristics and information of sporting activity are shown in Table 2.

The percentage of students who practiced sport at a competitive level was 21%; noncompetitive athletes were 41% whereas nonathletes were 38%. The list of sports included more than 35 disciplines (Fig. 1).

**ECG analysis**

Overall, abnormal ECGs (major and/or minor) were found on 16.3% (n = 1945) of the total cohort and are shown in Table 3. The prevalence of major abnormalities was 13% (n = 1547) whereas the prevalence of minor was 34% (n = 4035).

The more common major abnormalities were T-wave inversion/ST-segment depression (3.5%), right axial deviation (2.6%), left ventricular hypertrophy (2%), atrial enlargement (2%) and complete right bundle branch block (1.7%).

The analysis of the prevalence of each ECG abnormality in the three groups (nonathletes, noncompetitive athletes and competitive athletes) revealed that incomplete right bundle branch block (respectively, 20.2, 12.6 and 13.6%, P < 0.001), sinus tachycardia (7.3, 4.6 and 3%, P < 0.001), short PQ interval (3, 2.7 and 1.7%, P = 0.005), atrial enlargement (2.7, 1.7 and 1.3%, P < 0.001), Brugada-like ECG pattern (1.5, 0.4 and 0.4%, P < 0.001) and premature ventricular contraction (0.7, 0.4 and 0.4%, P = 0.049) were more common in nonathletes compared with the athletic groups. As expected, sinus bradycardia (respectively, nonathletes, noncompetitive athletes and competitive athletes: 2.8, 4.6 and 9.2%, P < 0.001), early repolarization (5.1, 4 and 6.5%, P < 0.001) and left ventricular hypertrophy (1.8, 1.8 and 2.9%, P = 0.004) were more common in competitive athletes. Complete right bundle branch block was more common in noncompetitive athletes (respectively, nonathletes, noncompetitive athletes and competitive athletes: 1.3, 2 and 1.7%, P = 0.030).

As the three groups were heterogeneous in terms of age and sex distribution, a multinomial logistic regression was performed. Results from the regression showed that ECG abnormalities were more common in nonathletes compared with noncompetitive athletes and competitive athletes (Table 4).

The prevalence of ECG abnormalities was stratified by age groups (<15, 16–17 and ≥18 years) and the variables presenting statistical difference are reported in Table 5. Specifically, the younger classes presented lower prevalence compared with other two older classes of age in terms of the following ECG abnormalities: T-wave inversion, complete RBB, right axial deviation, short QT interval, Brugada-like ECG pattern, short PQ interval, sinus bradycardia, early repolarization and sinus arrhythmias. Differences between the groups 16 and 17 and at least 18 years of age were observed only for Brugada-like ECG patterns and early repolarization (more prevalent in the older group) and sinus tachycardia (less prevalent in the older group).

One third of the students (33%) complained of symptoms: 20% palpitation; 11% chest pain; 7% dyspnea; 6.4% syncope. Among students with major ECG abnormalities
17% (n = 263) complained of palpitations, 8% (n = 128) chest pain, 6% (n = 89) dyspnea and 5% (n = 78) syncope. Among the students with ECG abnormalities, only 66 (1.1%) had a positive family history of SCD.

Follow-up analysis
Follow-up was achievable for 90% (n = 10,754) of enrolled students and no events were reported. For the remaining 10% (n = 1,195) of unavailable students, the Table 4

Table 3  ECG findings

| ECG finding                      | Total population (n = 11,949) | Nonathletes (n = 4,548) | Noncompetitive athletes (n = 4,946) | Competitive athletes (n = 2,455) |
|----------------------------------|------------------------------|-------------------------|-------------------------------------|---------------------------------|
|                                  | n   | %   | n   | %   | n   | %   | n   | %   | P-value |
| Major abnormalities              |     |     |     |     |     |     |     |     |         |
| T-wave inversion/ST-segment depression | 422 | 3.5 | 178 | 3.9 | 170 | 3.4 | 74  | 3.0 | 0.135   |
| Complete left bundle branch block | 1   | 0.0 | 0   | 0.0 | 1   | 0.0 | 0   | 0.0 | 0.493   |
| Complete right bundle branch block| 203 | 1.7 | 61  | 1.3 | 101 | 2.1 | 41  | 1.7 | 0.030   |
| Left anterior fascicular block    | 26  | 0.2 | 9   | 0.2 | 14  | 0.3 | 3   | 0.1 | 0.352   |
| Left/right atrial enlargement     | 239 | 2.0 | 124 | 2.7 | 83  | 1.7 | 32  | 1.3 | <0.001  |
| Left axis deviation               | 100 | 0.8 | 36  | 0.8 | 42  | 0.9 | 22  | 0.9 | 0.893   |
| Right axis deviation              | 315 | 2.6 | 132 | 2.9 | 119 | 2.4 | 64  | 2.6 | 0.319   |
| Ventricular preexcitation (WPW)   | 12  | 0.1 | 4   | 0.1 | 7   | 0.1 | 1   | 0.04| 0.412   |
| Long QT interval                  | 56  | 0.5 | 20  | 0.4 | 20  | 0.4 | 16  | 0.7 | 0.319   |
| Short QT interval                 | 127 | 1.1 | 49  | 1.1 | 38  | 0.8 | 35  | 1.4 | 0.089   |
| Brugada-like ECG pattern          | 97  | 0.8 | 68  | 1.5 | 19  | 0.4 | 10  | 0.4 | <0.001  |
| Premature ventricular contractions| 60  | 0.5 | 32  | 0.7 | 18  | 0.4 | 40  | 1.0 | 0.049   |
| Left ventricular hypertrophy      | 241 | 2.0 | 81  | 1.8 | 90  | 1.8 | 70  | 2.9 | 0.004   |
| Right ventricular hypertrophy     | 30  | 0.3 | 8   | 0.2 | 14  | 0.3 | 8   | 0.3 | 0.411   |
| Minor abnormalities               |     |     |     |     |     |     |     |     |         |
| First degree AV block             | 33  | 0.3 | 19  | 0.4 | 9   | 0.2 | 5   | 0.2 | 0.068   |
| Short PQ interval                 | 310 | 2.6 | 136 | 3.0 | 132 | 2.7 | 42  | 1.7 | 0.007   |
| Rhythm sinus coronary             | 61  | 0.5 | 19  | 0.4 | 26  | 0.5 | 16  | 0.7 | 0.015   |
| Junctional rhythm                 | 25  | 0.2 | 7   | 0.2 | 13  | 0.3 | 5   | 0.2 | 0.509   |
| Atrial premature beats            | 117 | 1.0 | 47  | 1.0 | 48  | 1.0 | 22  | 0.9 | 0.854   |
| Sinus bradycardia                 | 578 | 4.8 | 127 | 2.8 | 226 | 4.6 | 225 | 9.2 | <0.001  |
| Sinus tachycardia                 | 632 | 5.3 | 333 | 7.3 | 226 | 4.6 | 73  | 3   | <0.001  |
| Incomplete right bundle branch block| 1878| 15.7| 918 | 20.2| 625 | 12.6| 335 | 13.6| <0.001  |
| Early repolarization              | 589 | 4.9 | 232 | 5.1 | 197 | 4.0 | 160 | 6.5 | <0.001  |
| Sinus arrhythmia                  | 2291| 19.2| 1,084| 23.8| 817 | 16.5| 390 | 15.9| <0.001  |

ECG abnormalities presented in Table 1 were not reported if no cases were founded. Post hoc analysis results presented in case of overall P-value less than 0.05.

schools were directly contacted in order to assess if overall death, cardiac death, resuscitated cardiac arrest or diagnosis of cardiac disease occurred in the period under investigation and no cases of deaths were recorded.

Among the students who were referred to the local cardiologist for major ECG, 25 (1.6%) were finally diagnosed with cardiac disease, both structural or electrical: preexcitation syndrome 0.8% (n = 12); long QT syndrome 0.3% (n = 4); Brugada syndrome 0.2% (n = 3); hypertrophic cardiomyopathy 0.1% (n = 2); dilated cardiomyopathy 0.1% (n = 2).

Discussion
This is the largest prospective ECG screening study restricted to teenagers (13–19 years). The original aspect of the study is the comparison of the prevalence of ECG abnormalities between competitive athletes, noncompetitive athletes and nonathletes. ECGs were analyzed irrespectively of the athletic status. We found that ECG abnormalities are common in the general young population (16.3%) with higher prevalence in nonathletes compared with noncompetitive athletes or competitive athletes if adjusted for age and sex.

Subjects with major ECG abnormalities underwent further evaluation and 1.6% were found to have a cardiac disease at follow-up. No deaths occurred at 2 years, follow-up.
There are conflicting results on the utility of ECG as a screening program in the general population. The lack of agreement is partly because of different national regulations and programs and partly to different methodologies in recruitment and analysis. Corrado et al.\textsuperscript{12} for the first time showed that in Italy the implementation of the preparticipation screening program for sport eligibility, based on ECGs, resulted in a 90\% decrease in SCD in athletes, whereas the rate of SCD did not change significantly among unscreened nonathletes. Subsequent studies confirmed the incremental value of ECG for early identification of asymptomatic athletes who have potentially lethal heart disorders in athletes in different age groups.\textsuperscript{13–21} The role of ECG as a screening tool was supported also in studies involving the general population.\textsuperscript{22–26}

Data supporting the role of ECG as a screening tool comes from the UK national screening programs. Chandra et al.\textsuperscript{5} performed ECG screening in young subjects (aged 14–35 years) and compared athletes’ and nonathletes’ ECG findings using Corrado’s ECG Classification.\textsuperscript{27} Specifically, 21.8\% of nonathletes and 33\% of athletes ($P < 0.001$) had potentially pathological ECGs. This study included a wider range of ages compared with our cohort; the enrollment was based on voluntary participation and analyzed together nonathletes and noncompetitive athletes.

More recently, 26 900 young individuals (aged 14–35 years) were evaluated using a health questionnaire and ECGs and with secondary investigations in case of abnormal results. Authors found that the addition of an ECG to a health questionnaire increases the likelihood of identifying disease associated with SCD by five times and it is more cost effective for identifying serious disease compared with screening using a health questionnaire alone.\textsuperscript{6}

On the other hand, evidence from the USA demonstrated the failure of the screening program to detect cardiovascular disease at risk of SCD in the athletes and low statistical sensitivity of ECGs.\textsuperscript{28–30} Furthermore, the utility of ECG was criticized by the Israeli experience as they did not find any difference in mortality after the introduction of the ECG screening.\textsuperscript{31} However, this study was based on data collected by newspapers only.

Differences in results are related to different methodological aspects. First is the timing of the ECG screening. Among the aforementioned studies, some of them were focused on children,\textsuperscript{32} some of them on adolescents\textsuperscript{20,21} and others included a wide range of adults including elderly people.\textsuperscript{38} It is important to underline that some abnormal ECG findings are rarely detected before the age of 12 years and they can be identified later during adolescence whereas older people can reveal ECG changes related to coronary artery disease.

Another critical difference is the criteria used for the ECG analysis and the acquisition of the ECG. This aspect makes it difficult to compare prevalence of ECG abnormalities across different studies. However, data of our study are in keeping with results from the Chandra’s screen program.\textsuperscript{5} In our study, the ECG was acquired by cardiologists and the analysis was entrusted to expert cardiologists, decreasing the false-positive rates.

The ECG screening had several benefits. First of all, it permitted the diagnosis of occult disease known to be at risk of SCD and the subjects were recommended to refrain from training. Secondly, ECG abnormalities can identify subjects with phenotype negative at the screening time but with the need for future follow-up (students with major abnormality without evidence of structural heart disease by imaging modalities). In addition, the benefit of screening goes beyond the identification of the

### Table 5 ECG analysis stratified by age groups

| ECG finding                              | Age ≤ 15· years, n = 4,055 | Age 16–17 years, n = 2,974 | Age ≥ 18· years, n = 4,920 | P-value A vs. B | P-value A vs. C | P-value B vs. C |
|------------------------------------------|-----------------------------|-----------------------------|-----------------------------|-----------------|-----------------|-----------------|
| Major abnormalities                      |                             |                             |                             |                 |                 |                 |
| T-waves inversion/ST-segment depression  | 86                          | 21                          | 42                          | 210             | 4.3             | <0.001          |
| Complete right bundle branch block       | 23                          | 0.6                         | 65                          | 2.2             | 115             | 2.3             | <0.001          | <0.001          | <0.001          | 1               |
| Right axis deviation                     | 15                          | 0.4                         | 110                         | 3.7             | 190             | 3.9             | <0.001          | <0.001          | <0.001          | 1               |
| Short QT interval                        | 7                           | 0.2                         | 44                          | 1.5             | 76              | 1.5             | <0.001          | <0.001          | <0.001          | 1               |
| Brugada-like ECG pattern                 | 0                           | 0                           | 21                          | 0.7             | 76              | 1.5             | <0.001          | <0.001          | <0.001          | 1               |
| Right ventricular hypertrophy            | 6                           | 0.1                         | 15                          | 0.5             | 9               | 0.2             | 0.006           | 0.038           | 0.062           |
| Minor abnormalities                      |                             |                             |                             |                 |                 |                 |
| First degree AV block                    | 4                           | 0.1                         | 10                          | 0.3             | 19              | 0.4             | 0.028           | 0.156           | 0.04            | 1               |
| Short PQ interval                        | 32                          | 0.8                         | 113                         | 3.8             | 165             | 3.4             | <0.001          | <0.001          | <0.001          | 1               |
| Atrial premature beats                   | 24                          | 0.6                         | 27                          | 0.9             | 66              | 1.3             | 0.002           | 0.472           | 0.002           | 0.325           |
| Sinus bradycardia                        | 127                         | 3.1                         | 156                         | 5.2             | 295             | 6               | <0.001          | <0.001          | <0.001          | 0.577           |
| Sinus tachycardia                        | 234                         | 5.8                         | 185                         | 6.2             | 213             | 4.3             | 0.001           | 1               | 0.006           | 0.001           |
| Early repolarization                     | 37                          | 0.9                         | 168                         | 5.6             | 384             | 7.8             | <0.001          | <0.001          | <0.001          | 0.001           |
| Sinus arrhythmia                         | 180                         | 4.4                         | 736                         | 24.7            | 1,375           | 27.9            | <0.001          | <0.001          | <0.001          | 0.008           |

AV, atrioventricular.
student at risk of SCD as it often triggers the evaluation of first-degree relatives who may also be at risk from inherited cardiac diseases.

Study limitation
The study is based on voluntary participation; accordingly selection bias could not be excluded. No students with known cardiac disease were present in the cohort. Accordingly, we could not exclude the possibility of underestimating the real prevalence of ECG abnormalities and cardiac diseases. Our results are based mainly on a Caucasian cohort (97.5%) and may not reflect the findings in other ethnicities. Data collection on sport activity was limited to sport category and competitive vs. non-competitive status while the number of hours of training per week was not recorded. The same ECG definitions were applied to the entire cohort without differences among subgroups. Although this approach could slightly increase the detection of minor abnormalities, it did not have any impact on major ECG abnormalities. Moreover, this approach avoided underestimating the prevalence of ECG abnormalities in the subgroup of students exposed to less intense sport and with shorter duration. The follow-up is limited to up to 24 months and including only phone calls, possibly accounting for the absence of SCD observed in this study. The prevalence of the symptoms reported was collected using a questionnaire. This could explain the relatively high prevalence of symptoms reported compared with the low prevalence of cardiovascular diseases diagnosed.

Conclusion
This study assessed the prevalence of ECG abnormalities in the general young population comparing the different groups: sedentary subjects, non-competitive athletes and competitive athletes. We found that, among a population of 11 949 consecutive teenagers, 13% had major ECG abnormalities requiring further investigations and leading to a diagnosis of cardiac disease potentially associated with SCD in 1.6%. Nonathletes had a higher incidence of ECG abnormalities compared with the athletic groups. Our results are in line with the data supporting ECG screening in the general young population.

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Conflicts of interest
There are no conflicts of interest.

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