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Prevalence of abnormal electrocardiograms in a large, unselected population undergoing pre-participation cardiovascular screening

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Aims The implementation of 12-lead ECG in the pre-participation screening of young athletes is still controversial and number of issues are largely debated, including the prevalence and spectrum of ECG abnormalities found in individuals undergoing pre-participation screening.

Methods and results We assessed a large, unselected population of 32 652 subjects [26 050 (80%) males], prospectively examined in 19 clinics associated to Italian Sports Medicine Federation. Most were young amateur athletes, aged 8–78 years (median 17), predominantly students (68%), engaged predominantly in soccer (39%), volleyball or basketball (8% each), athletics (6%), cycling (5%), swimming (4%). The ECG patterns were evaluated according to commonly used clinical criteria. The 12-lead ECG patterns were considered normal in 28 799 of the 32 652 athletes (88.2%) and abnormal in 3853 (11.8%). The most frequent abnormalities included prolonged PR interval, incomplete right bundle branch block (RBBB) and early repolarization pattern (total 2280, 7.0%). Distinct ECG abnormalities included deeply inverted T-waves in >2 precordial and/or standard leads (751, 2.3%), increased R/S wave voltages suggestive of LV hypertrophy (247, 0.8%), conduction disorders, i.e. RBBB (351, 1.0%), left anterior fascicular block (162, 0.5%), and left bundle branch block (19, 0.1%). Rarely, cardiac pre-excitation pattern (42, 0.1%) and prolonged QTc interval (1, 0.03%) were found.

Conclusion In a large, unselected population of young athletes undergoing pre-participation screening, the prevalence of markedly abnormal ECG patterns, suggestive for structural cardiac disease, is low ($<5\%$ of the overall population) and should not represent obstacle for implementation of 12-lead ECG in the pre-participation screening program.

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Introduction

Sudden and unexpected deaths in young competitive athletes are uncommon but highly visible events, which raise concern and reiterate debate in both lay public and medical community with particular regard to the feasibility and the efficacy of pre-participation cardiovascular screening.[1–6]

The implementation of 12-lead ECG in the screening program has been supported in the recent years by the Sport Cardiology Section of the European Society of Cardiology and the Medical Commission of the International Olympic Committee for all individuals engaged in competitive sports,[7,8] based on the recognition that abnormal ECGs may identify (or raise suspicion for) hypertrophic cardiomyopathy (HCM) and other cardiomyopathies, which are responsible for most of the athletic field deaths.[9,10] Moreover, the implementation of the pre-participation screening program routinely including the 12-lead ECG has been shown to reduce mortality in large population of competitive athletes, due to timely identification of individuals with silent cardiomyopathies and subsequent disqualification from competitive sport.[11]

However, the implementation of the 12-lead ECG into the screening programs is still debated and raises clinical concern, mostly due to the expected large proportion of abnormal ECG patterns in young trained athletes,[12] which would require additional diagnostic testing to confirm (or exclude) the presence of underlying cardiovascular disease.[13]

In the present investigation, therefore, we addressed this problem by assessing the prevalence and the spectrum of ECG abnormalities found in a large and unselected population of young subjects undergoing the pre-participation screening, routinely including the 12-lead ECG.

Methods

Italian pre-participation screening program

Systematic pre-participation screening of competitive athletes is a medical program established by law and implemented in Italy since 1982.[5] According to this program, all individuals participating in organized, competitive sport activities are required to undergo a preventive medical and cardiovascular evaluation, which routinely includes 12-lead ECG, in addition to personal and family history and physical examination (with measurement of blood pressure). Physicians primarily responsible for pre-participation screening are in Italy, licensed specialists in sport medicine, who attend a full-time post-graduate residency program for 4 years.[5]

Pre-participation screening evaluation is usually performed in sports clinics, which are present in virtually all major communities of >10 000 population across the country. An estimated population of over 3 million young competitive athletes are evaluated annually throughout Italy within this screening program to exclude the presence of cardiovascular disease.

Athletes judged to be free of cardiovascular disease (or other limiting conditions) obtain a certification of eligibility for competitive sports. On the other hand, athletes in whom an ECG abnormality is found, raising suspicion for cardiovascular disease, are referred to major hospital and clinical centres to confirm cardiac diagnosis and assess their eligibility for competitive sports.

Study population

The study population included 32 652 subjects [26 050 (80%) males and 6602 (20%) females], who were prospectively examined in one of the 19 sports clinics throughout Italy associated with the Italian Sports Medicine Federation, in the period from 1 January to 31 December 2003.

Athletes aged 22.3 ± 12.5 years (range 8–78, median 17), the height was 167.0 ± 13.9 cm (110–207), weight 62.8 ± 16.3 kg (36–156). Majority of subjects were young, with the largest proportion in the age range 11–20 years (54% of the study sample), with individuals >35 years representing only 15% of the study population. Most were students (68% of overall population). The largest proportion comprised individuals entering the athletic activities for the first time, or amateur athletes engaged predominantly in soccer (39%) and, to a lesser extent, in volleyball or basketball (8% each), athletics (6%), cycling (5%), swimming (4%), martial arts, tennis, and gymnastics (3% each). The average time spent in sports activities was 4–6 h per week in the majority of individuals (54%) and was <3 or >6 h per week in the remaining cases (18% each).

Electrocardiography

Standard 12-lead ECGs were performed with the subject in supine position during quiet respiration and recorded at 25 mm/s. ECG tracings were usually obtained at least 24 h following the last athletic activity. ECG patterns were evaluated according to the commonly adopted clinical criteria.[12] Specifically, the following criteria were considered as evidence of ECG abnormality: increased $S_1+R_{5,6}$ wave voltage ≥35 mm in precordial leads and/or increased R-wave >15 mm in peripheral lead I and/or >12 mm in aVL (suggestive for LV hypertrophy); depressed ST-segment and/or deeply inverted T-waves in >2 precordial and/or standard leads (exclusive of lead III); prolonged P-wave duration of 0.12 s in standard leads I or II with negative portion of the P-wave ≥1mm in depth and ≥0.04 s in duration in lead V1 (consistent with left atrial enlargement); the RSR^1 pattern in anterior precordial leads of ≥0.12 s consistent with right bundle branch block (RBBB); QRS axis deviation ≤ −30° suggestive for left anterior fascicular block (LAFB); the left bundle branch block (LBBB) was defined as QRS duration ≥0.12 s. The pre-excitation pattern (PEC) was identified by presence of reduced PR interval (<0.12s) with evidence of delta wave; the prolonged corrected QT interval was defined as QTc >0.44 s in males and >0.46 s in females. Finally, we also recorded the prolonged PR interval (>0.20 s), the incomplete RBBB (the RSR^1 pattern in anterior precordial leads of <0.12 s) and the early repolarization pattern (the upward ST-segment elevation in ≥2 peripheral or precordial leads, beginning from an elevated J point and continuing with an upsloping shape into the T-wave).

Statistical analysis

For all the variables, standard statistical indices (mean, median, and standard deviation) were calculated and distribution of frequencies of variables was assessed. The relationship between type of sport and ECG abnormalities was assessed by selecting the sports disciplines participated by large subset of athletes, identified as with ≥1000 participants (i.e. track&field, soccer, racing bike, martial sports, swimming, basketball, and volleyball), and the relationship of ECG abnormalities with age was assessed by dividing the overall population in three age groups (i.e. <20, 20–29, and ≥30 years). Comparison of the proportions were assessed by two-sided *z* test. A *P*-value of <0.05 was considered evidence of statistical significance.[14]

Results

Prevalence of abnormal electrocardiography patterns

The ECG patterns were considered normal in the vast majority of athletes, i.e. 28 799 of the 32 652 (or 88.2%); abnormal patterns were identified in the remaining 3853 subjects (11.8%). The spectrum of ECG abnormalities found in the overall study population is shown in *Table 1*. The

Table 1 Prevalence of ECG abnormalities in an unselected population of 32 652 young individuals undergoing the pre-participation cardiovascular screening

ECG abnormalities	Athletes, *n* (%)
Negative T-waves in precordial/standard leads	751 (2.3)
RBBB	351 (1.0)
Increased R/S wave voltages (suggestive of LVH)	247 (0.8)
Left anterior fascicular block	162 (0.5)
Pre-excitation pattern	42 (0.1)
LBBB	19 (0.1)
Prolonged corrected QT interval	1 (0.003)
Others (incomplete RBBB, prolonged PR interval, early repolarization pattern)	2280 (7.0)
Total	3853 (11.8)

RBBB, right bundle branch block; LVH, left ventricular hypertrophy; LBBB, left bundle branch block.

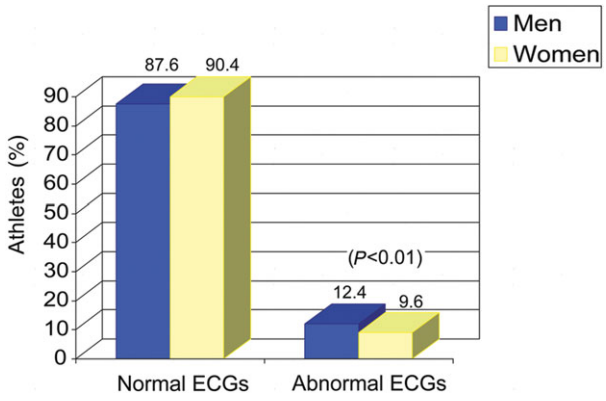

Figure 1 Prevalence of ECG patterns according to gender.

most frequent abnormalities included prolonged PR interval, incomplete RBBB and early repolarization pattern, which together accounted for 59.19% of all anomalies (and the 7% of the overall study population).

In the remaining cases, which represented the 40.81% (CI 4.807–4.812) of all ECG abnormalities (and 4.8% of the overall population), distinctly abnormal patterns were found, including diffusely inverted T-waves in precordial and/or standard leads (751, 2.3%), increased R/S wave voltages suggestive of LV hypertrophy (247, 0.8%), cardiac conduction disorders, either RBBB (351, 1.0%), LAFB (162, 0.5%), or LBBB (19, 01%). Less frequently, cardiac PEC (42, 0.1%) and prolonged QTc interval (1, 0.03%) were observed.

Relation of abnormal ECG patterns with gender, age, and type of sport

The prevalence of ECG abnormalities was higher in males than in females (12.4 vs. 9.6%; $P = 0.001$) (*Figure 1*). The prevalence of ECG abnormalities was also different in respect to age, with proportion of prolonged PR interval, incomplete RBBB, and early repolarization pattern being larger in the younger individuals, and inverted T-waves in precordial and/or standard leads, increased R/S wave voltages suggestive of LV hypertrophy, and cardiac conduction

Table 2 Different types of ECG abnormalities in relation to age, in an unselected population of 32 652 young individuals

	≥20 years ($n = 2430$) %	20–29 years ($n = 579$) %	≥30 years ($n = 844$) %
Inc. RBBB, prolonged PR, ER pattern	73.1	37.9	30.1
Inverted T-waves	9.5	38.6	37.9
Increased R/S wave voltages	3.1	4.6	7.2
RBBB	10.9	12.1	10.9
LAFB, LBBB	2.1	5.7	13.3
Pre-excitation pattern	1.3	1.1	0.6

Values represent the percent of ECG abnormalities as part of the total in each age group.

Inc. RBBB, incomplete right bundle brunch block; ER, early repolarization; RBBB, right bundle brunch block; LAFB, left anterior fascicular block; LBBB, left bundle brunch block.

disorders more frequent in adult subjects, as shown in *Table 2*. The differences of the proportions among age groups were statistically significant ($P < 0.001$).

Finally, with regard to type of sport discipline, individuals engaged in basketball, volleyball, and soccer showed larger proportion of early repolarization pattern, prolonged PR interval and incomplete RBBB, while cyclists had larger proportion of increased R/S wave voltages, ventricular conduction delays and inverted T-wave patterns in comparison with other sports. The differences of the proportions among types of sport were statistically significant ($P < 0.001$).

Rhythm disturbances on the baseline 12-lead electrocardiography

In addition, minority of athletes (1170, or 3.6%) also showed rhythm disturbances on the baseline 12-lead ECG. Large proportion (340, or 1.0%) consisted of marked sinus bradycardia; other abnormalities included supraventricular ectopic beats (377, or 1.1%) or ventricular ectopic beats (VEBs) (349, or 1.1%). By far less commonly, supraventricular tachycardia (29, or 0.09%), atrial flutter/fibrillation (5, or 0.02%), polymorphic VEBs (40, or 0.1%), or non-sustained ventricular tachycardia (3, or 0.01%) were observed. Also, atrioventricular block (second degree, type 1) was rarely found at baseline ECG (14, or 0.04%).

Discussion

Strategies to prevent sudden death in young athletes continue to generate substantial debate,[1,3–6] with special emphasis on the efficacy of pre-participation cardiovascular screening for timely identification of individuals at risk.[5,9,10] Recently, Corrado *et al.* demonstrated that implementation of pre-participation cardiovascular screening routinely including the 12-lead ECG, as recommended by the European Society of Cardiology[7] and International Olympic Committee,[8] is efficient to reduce mortality in large populations of young competitive athletes, due to timely recognition of individuals with silent cardiomyopathies and their withdrawal from sport activities.[11]

However, the implementation of the 12-lead ECG into the pre-participation screening still raises a number of unsolved questions, such as the large proportion of abnormal ECGs expected in young trained individuals. There is widely diffuse clinical perception, substantiated by previous reports,[12,15] that abnormal ECG patterns are largely common in athlete populations, which would require additional cardiovascular testing to resolve the ambiguity of the diagnosis, by disproportionately raising the costs of the screening.[13]

In the present study, we addressed this question, by assessing the prevalence of ECG abnormalities in a large and unselected population of young athletes participating in a broad spectrum of sport disciplines. Our investigation showed that ECG abnormalities were present in about 12% of these individuals. This proportion is mildly greater than previously reported in the population living in the Veneto region (i.e. 9%, which included either the abnormal ECG patterns and/or positive family history and/or abnormal physical examination).[9]

The main finding of our investigation was that the largest proportion of ECG abnormalities (i.e. about 60%) in individuals undergoing pre-participation screening comprised early repolarization pattern, incomplete RBBB, and prolonged PR interval, which are commonly regarded as innocent electrocardiographic changes associated with the 'athlete's heart' and deprived of clinical significance.[12,16–18]

The ECG abnormalities which raised clinical suspicion for underlying cardiac disease, mandating additional diagnostic testing, were restricted to the remaining 40% of the abnormal ECGs corresponding to only 4.8% of the overall athlete population. According to our experience, therefore, only a minority of individuals undergoing the pre-participation cardiovascular screening would require additional diagnostic testing, a finding which largely minimizes the current clinical concern regarding routine implementation of the 12-lead ECG into the screening program.

Although less than previously believed, this study also confirms that a small subset of adolescent and young individuals entering the athletic activity show certain ECG abnormalities which raise justified clinical suspicion and require supplementary diagnostic testing to resolve the problem of cardiovascular diagnosis and assess the risk associated with participation in competitive sports. In these instances, screening may raise relevant controversies regarding cardiovascular diagnosis, eligibility to competitive sports, as well as legal and insurance problems.[13]

Prevalence of abnormal ECGs was larger in male compared with female individuals, which was somewhat expected and consistent with our previous investigation in elite athletes reporting larger proportion of abnormal ECGs in males compared with females.[12] Lower prevalence of abnormal ECGs in females is likely due to several (and not completely known) factors, including the lesser extent of LV remodelling.[19]

From this analysis, it was evident that types of ECG anomalies are different in accord to age group. In the younger individuals (i.e. $<$20 years) the largest proportion of the ECG anomalies includes prolonged PR interval, incomplete RBBB, and early repolarization pattern, while in the adult individuals abnormal repolarization patterns (diffusely inverted T-waves), increased R/S wave voltages suggestive of LV hypertrophy, and major cardiac conduction disorders are prevalent. This trend likely expresses the effect of the screening process, which may have allowed identification of most innocent ECG changes at the initial screening evaluation, when young individuals enter the athletic activities. The prevalence of the ECG criteria suggestive for LV hypertrophy and major conduction delays in adult age may be compatible with identification of cardiomyopathies later in life, which is consistent with the delayed phenotypic expression of these diseases in certain individuals.[20,21]

It is worthy to notice, however, that the results of the present analysis may not be applicable to all athlete populations, and the prevalence of abnormal ECG patterns may be different in relation to demographic, ethnic, and training characteristics of athlete populations. For instance, we compared the abnormal ECG patterns in the present population with those reported in elite junior athletes by Sharma *et al.*[15] and in elite adult athletes from our previous investigation[12] (*Table 3*). Although a measure of caution is needed when comparing the results, nevertheless it is evident the largest proportion of ECG abnormalities in all athletes comprised those changes (i.e. incomplete RBBB, prolonged PR interval, and early repolarization pattern) which are believed to be innocent expressions of the 'athlete's heart'.

Other ECG changes suggestive for LV hypertrophy (such as the increased R/S voltages in precordial or standard leads) are much more frequent in elite junior and adult athletes compared with adolescent individuals entering the athletic activities. This finding may be the consequence of the more substantial cardiac remodelling associated with intensive exercise conditioning in elite athletes, and may also explain the larger proportion of overall abnormal patterns we previously described in adult competitive athletes compared with young amateur individuals of the present study (14 vs. 5%; $P < 0.001$).[12]

Table 3 Comparative proportions of ECG abnormalities observed in the present and previous[12,22] athlete populations, in relation to age and level of achievement

	Young amateur athletes ($n = 32\,652$) %	Junior elite athletes[22] ($n = 1000$) %	Adult elite athletes[12] ($n = 1005$) %
Incomplete RBBB, prolonged PR interval, early repolarization	7	43	34
Voltage criteria for LVH	0.8	45	40
Negative T-waves in precordial/standard leads	2.3	4	2.7

Study limitation

It is worthy to notice that, because of the study design, we did not have access to data describing the diagnostic testing performed and the final cardiac diagnosis in the individuals with abnormal ECG patterns at the screening. Therefore, the prevalence of structural heart disease in subjects with ECG abnormalities remained unknown, and the important question of false-positive test results unresolved. Indeed, no data were available on the incidence of cardiac events (including sudden death) in individuals presenting an abnormal ECG at the screening.

Indeed, although the issue of false-negative test results has not been approached in this study, in a recent analysis we found that the negative ECG patterns are highly predictive for absence of HCM (and other cardiac disease).[10]

Finally, it was somewhat surprising that certain ECG abnormalities, such as the Brugada syndrome (or other channelopathies)[22] were not reported in our population. This observation emphasizes the need for a continued educational program for physicians in the effort to improve efficacy of the cardiovascular screening program.

In conclusion, our experience suggests that in a large and unselected population of young individuals undergoing cardiovascular screening, the prevalence of markedly abnormal ECG patterns suggestive for structural cardiac disease is low (<5%), and should not represent obstacle for implementation of 12-lead ECG in the pre-participation screening program.

Conflict of interest: none declared.

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