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Evolutionary Aspects of the Resting Electrocardiogram after One Year of Regular Training in Young Senegalese Elite Athletes

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Abstract

Introduction: ECG changes are observed depending on the nature and duration of the athlete's physical training. The evolution of these ECG modifications remains little known. Thus, our work aimed to examine the evolution of resting ECG parameters in elite athletes after a year of regular training. **Material and methods:** A prospective longitudinal (paired) study was carried out during the period from October 20, 2022, to November 20, 2023. The study population consisted of young basketball players, all male, who had 10 hours of weekly training for at least one year. The participants were examined at the functional exploration department of the Thies regional hospital, where they benefited from a clinical examination followed by the performance of an ECG recording during October 2022 and 2023. **Results:** A total of 16 elite basketball players with a weekly training volume of 15 hours were recruited, with an average age of 17.4 years. The study population had an average BMI of 19.6 kg/m^2. Comparative analysis of cardiovascular data revealed a significant decrease in heart rate ($p = 0.001$) and systolic blood pressure ($p = 0.0002$) between 2022 and 2023. A significant increase in the frequency of sinus bradycardia was observed in athletes, with percentages of 69% in 2022 versus 75% in 2023 ($p = 0.005$). The same is true for the frequencies of left atrial enlargement and biventricular hypertrophy, the percentages of which increased, respectively, from 2022 to 2023, from 6.25% to 44% and from 13% to 38% ($p = 0.04$ and $p < 0.0001$). However, we did not find any correlation between anthropometric parameters and ECG data. **Conclusion:** Endurance training leads to physiological cardiovascular adaptations. These electrical changes are correlated with both training and the length of time spent exercising and are known to be reversible upon cessation of physical training.

Keywords

ECG, Elite Athlete, Athlete's Heart, African

1. Introduction

Sports practice has become widely democratized these days and can be observed at all ages and levels. However, the scientific literature remains well documented today concerning the specific electrocardiographic (ECG) alterations observed in elite athletes regardless of age and sex. Indeed, several classifications [1]-[3] have succeeded one another in order to limit errors in the interpretation of ECG tracings in athletes. These successive classifications have made it possible to reduce the additional cost of screening, in particular by reducing the demand for additional explorations resulting from an erroneous interpretation of the ECG [4]. These different classifications confirm that ECG changes are to be noted according to the morphotype [5], according to the race [6], and according to the degree of training [7] of the athlete. However, the evolutionary nature of the ECG modifications observed in high-level athletes remains little studied. Thus, the aim of this work was to examine the evolutionary aspects of the resting ECG changes in elite athlete after one year of regular physical training.

2. Material and Methods

2.1. Type and Period of Study

This was a prospective longitudinal (paired) study conducted from October 20, 2022, to November 20, 2023. We compared the clinical and ECG data of athletes from 2022 with those from 2023.

2.2. Study Population

Our study population consisted of young male basketball players playing in the city of Thies (Senegal). Recruitment took place at a sports center basketball training study. The study was performed according to the principles expressed in the Declaration of Helsinki. All subjects agreed to participate voluntarily in the study after giving their free and informed consent.

- **Inclusion criteria**

  We included in this study:

➢ Subjects aged between 15 and 25 years;
➢ Athletes who have benefited from the annual medical examination for the years 2022 and 2023;
➢ High-level basketball players with at least 10 hours of weekly training, without any interruption in training noted for more than one week.

- **Non-inclusion criteria:**

The following subjects were not retained in the study:

- subjects declaring a voluntary refusal to participate in the study;
- Athletes with less than one year of seniority in the center;
- Athletes who have traveled outside the country or who have demonstrated irregularity in training due to illness for more than one week during the study period.

2.3. Methodology

The athletes were examined in the functional exploration department of the Regional Hospital Center of Thies. The study was concluded by performing ECG recordings, each preceded by a clinical examination, for all subjects during October 2022 and October 2023. The medical interview was guided by a survey form covering civil status (name, age), possible symptoms (at rest or during exercise), and personal and family history of the athletes. Anthropometric and cardiovascular data were collected, which subsequently allowed for the calculation of body mass index (BMI) using the Quetelet index [8], and mean blood pressure (MBP) using the Lian formula [9] according to the following formula: $MBP = (SBP + 2 \times DBP)/3$.

Regarding the ECG recording, the paper speed was 25 millimeters (mm) per second with a calibration of 10 millimeters for 1 millivolt (mV). Each trace included, in addition to the 12 standard leads, a long recording of lead D2. To prevent bias, two independent reviewers are frequently blinded to athlete data to ensure an objective interpretation. An initial read is performed by a physiologist, followed by a second over-read by a cardiologist who is blinded to the initial findings. For standardization, all reviewers often follow specific guidelines, such as the ESC interpretation criteria, to ensure consistency in their interpretation. Disagreements between reviewers are often resolved through discussion and in some cases by consulting a senior expert.

Different ECG parameters were evaluated:

- The heart rate (HR) was determined by considering the RR interval over three successive QRS complexes when the rhythm was regular, and the calculation consisted of taking the average of the two frequencies obtained using the 1500/RR ratio. In cases of irregular rhythm, heart rate was calculated by counting the number of QRS complexes over a 10-second interval and multiplying this number by six;
- sinus or non-sinus rhythm;
- the duration and amplitude of the P wave, allowing the search for left or right atrial enlargement, respectively;
- atrioventricular conduction, looking for atrioventricular blocks or a short PR interval;
- intraventricular conduction in search of bundle branch blocks;
- repolarization by evaluating the ST segment, the T wave, and the QT interval, looking for an early repolarization pattern described as an elevation of at least

0.1 mV of the J point, followed by an elevated ST segment, more often concave at the top and generally followed by a large positive T wave. The elevations or depressions of the ST segment were sought in the different derivations, taking into account the amplitude, which is at a value greater than or equal to 1 mm.

T waves were also described, emphasizing their negativity and inversion. The QT duration measured (QTm) on lead V5 was given in milliseconds (ms); the corrected QT (QTc) is calculated by the Bazett formula: $QTc = QTm/\sqrt{RR}$. Long QT was defined in the general population by a QTc threshold value ≥ 440 ms in men. While the QTc duration limits proposed in the general population remain appropriate for moderately trained athletes, in high-level athletes it is recommended to retain the limits of 470 ms for men [3]. The QTc duration, which should not be limited to automatic measurement, was manually confirmed by the classic tangent method.

Furthermore, given its mathematical limitations, the correction by the classic Bazett formula underestimates the QT duration in cases of bradycardia (HR < 60 bpm). This underestimation is clear as soon as the HR is less than 50 bpm, which is not uncommon in endurance athletes. The Sokolow-Lyon index was used to determine left ventricular hypertrophy (LVH). This index is calculated by the sum of the amplitude of the S wave in V1 (SV1) and that of the R wave in V5 or V6 (RV5 or RV6), defining LVH when it is greater than 35 mm [10].

2.4. Data Processing

Data collection was carried out using pre-established survey forms, and the interpretation of ECG tracings was performed using *Microsoft Excel* 2021 and *R software* (*version* 4.5.1). Quantitative variables were expressed as mean ± standard deviation (SD). Qualitative variables were presented as percentages. Comparison of means was performed using the paired Student's t-test, and the Chi-square test was used to compare percentages for categorical variables. Relationships between parameters were assessed using Pearson's correlation test. A p-value less than 0.05 ($p < 0.05$) was considered statistically significant.

3. Results

Twenty basketball players were recruited in 2022, of whom four were not retained (three due to sick leave exceeding one week and one athlete due to travel to the United States in March 2023). Thus, the study population consisted of 16 young, high-level male basketball players, with a weekly training volume of more than 10 hours, *i.e.*, sessions of 2 hours and 30 minutes per day for 6 days per week. In general, a training session begins with a warm-up followed by an hour of skill drills, which include dribbling, passing, footwork, finishing, and shooting. The rest of the training focuses on team identity, covering collective defense, collective offense, rebounding, and special situations. All participants reported no family history of sudden cardiovascular death.

3.1. General Characteristics

The characteristics of the study population are summarized in Table 1. Participants had a mean age of 17.4 ± 1.3 years, ranging from 15 to 19 years. The mean body mass index (BMI) was 19.6 ± 2.3 kg/m².

Table 1. General characteristics of the study population in 2022.

Anthropometric parameters	Mean ± standard deviation	Median	Min - Max
Age (years)	17.4 ± 1.3	18	15 - 19
Weight (kg)	72.8 ± 12.5	70.6	49.3 - 102
Height (m)	1.92 ± 0.1	1.91	1.78 - 2.08
BMI (kg/m²)	19.6 ± 2.3	20.3	16.6 - 24.3

3.2. Anthropometric Parameters

The anthropometric parameters summarized in Table 2 remained relatively constant, with no significant variations observed between 2022 and 2023.

Table 2. Comparison of anthropometric parameters.

Cardiovascular parameters	2022	2023	p-value
Weight (Kg)	72.8	76.5	0.25
Height (m)	1.92	1.94	0.27
BMI (Kg/m²)	19.6	20.2	0.23

3.3. Cardiovascular Parameters

Table 3 summarizes the mean values of cardiovascular parameters. Comparison of these cardiovascular data revealed a significant decrease in the athlete's heart rate ($p = 0.001$) and systolic blood pressure (SBP) ($p = 0.0002$). However, diastolic blood pressure (DBP) values remained relatively constant.

Table 3. Comparison of average cardiovascular parameters.

Cardiovascular parameters	2022	2023	p-value
HR (bpm)	61	58	**0.001**
SBP (mmHg)	123.8	111.5	**0.0002**
DBP (mmHg)	70.5	70	0.85
MBP (mmHg)	87.9	84.6	0.13

3.4. Electrocardiographic Data

- **Study of electrocardiographic parameters**

The heart axis was normal in all participants for both different tracings performed. No significant variations were observed regarding the means of the electrocardiographic parameters listed in Table 4 below.

Table 4. Comparison of the averages of electrocardiographic parameters.

ECG parameters	2022	2023	p-value
QRS axis (˚)	74.7	72.2	0.12
P wave amplitude (mm)	1.6	1.8	0.5
P wave duration (ms)	96.9	97.8	0.8
PR interval (ms)	163	167.5	0.4
QRS in V1 (mm)	90.3	92.6	0.39
QRS in V5 (mm)	76.6	77.5	0.6
Sokolow-Lyon index (mm)	42	42.8	0.5
QT corrected (ms)	415.9	413.6	0.63

- **Frequencies of specific ECG changes**

All study participants exhibited at least one electrocardiographic change during the two ECG recordings carried out in 2022 and 2023. As show in Figure 1, a significant increase in the frequency of sinus bradycardia was observed, rising from 69% in 2022 to 75% in 2023 ($p = 0.005$), which aligns with literature reports showing sinus bradycardia in up to 80% - 90% of high-level athletes as a physiological adaptation to endurance training. Similarly, the frequencies of left atrial enlargement (LAE) and biventricular hypertrophy (BVH) increased significantly from 6.25% to 44% and from 13% to 38%, respectively ($p = 0.04$ and $p < 0.0001$). However, no correlation was found between anthropometric parameters and resting electrocardiographic data in these athletes.

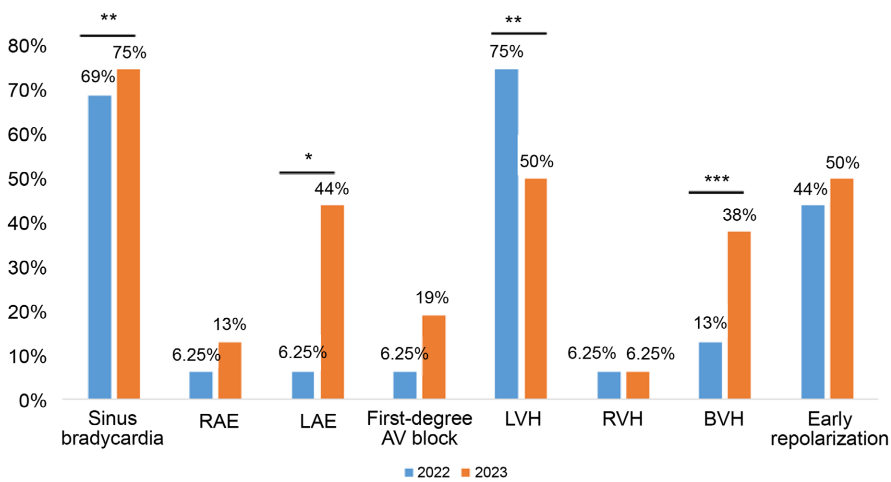

Figure 1. Comparison of the proportions of ECG changes. RAE: right atrial enlargement; LAE: left atrial enlargement; LVH: left ventricular hypertrophy; RVH: right ventricular hypertrophy; BVH: biventricular hypertrophy.

4. Discussion

Athletes frequently exhibit ECG changes as a consequence of cardiac adaptations to the increased physiological demands imposed by intense physical training [11], as confirmed by the results of our study. These electrical signs can sometimes mistakenly simulate a pathology and wrongly lead to not signing the certificate of no contraindication to the practice of competitive sport, given the spectrum of sudden death to which elite athletes are exposed [7] [12]. ECG abnormalities resolve after detraining but persist with regular high-intensity training [11]. These findings highlight the necessity of comprehensive and evolving cardiac monitoring in young athletes.

The ECG changes in athletes are dominated in this study by sinus bradycardia, first-degree atrioventricular block, left atrial enlargement (LAE), left ventricular hypertrophy (LVH), biventricular hypertrophy (BVH), and early repolarization.

Clinical data

The young average age of the study population (17.4 ± 1.3 years) corroborates the results of the work of Affangla *et al.* carried out on high-level basketball players with an average age of 15 ± 1.56 years in 20 basketball players [13]. The young age of the study population could be explained by the practice of basketball from an early age, because it is the second most practiced team sport in Senegal after football. In addition, the advent of sports-study centers, which welcome very young residents, constitutes a means that will allow certain talented young people to quickly access elite sport from adolescence.

The average body mass index (BMI) was normal (19.6 kg/m²), with, in particular, a relative constancy of anthropometric parameters between 2022 and 2023. This phenomenon could be justified by the boarding school status of the recruited residents, whose feeding and training sessions were entirely managed by technical staff.

Comparison of cardiovascular data revealed a significant decrease in the athlete's heart rate (HR) ($p = 0.001$) and systolic blood pressure ($p = 0.0002$). This remains in agreement with the data described in the literature, demonstrating in particular a decrease in heart rate and especially in systolic blood pressure values [14]. Regular practice of adapted physical activity (PA) leads to a decrease in blood pressure values, provided that this PA is of moderate intensity and of sufficiently long duration. This protective effect of PA on the heart is explained by the cardiac remodeling observed in trained subjects compared to sedentary subjects (myocardial hypertrophy, increase in end-diastolic volume and relaxation speed), leading to an increase in maximum cardiac output and maximal oxygen consumption (VO2 max). Regular PA (4 to 5 weekly sessions) helps counteract cardiovascular physiological aging by improving ventricular compliance and distensibility [15]. Furthermore, physical training helps reduce resting HR and recovery speed after exercise. The lower resting HR thus offers athletes a broader physical capacity, the maximum heart rate (HR max) being fixed for a given subject and at a given age. This beneficial adaptation is linked to the increase in cardiac parasympathetic tone. In addition, vasodilatory endothelial function is improved, which increases the bioavailability of nitric oxide, including at the level of the coronary microcirculation [16]. Production of protective cytokines and circulating endothelial precursors has also been demonstrated. At the cardiomyocyte level, biological adaptations were found at the level of the translation of SERCA2 and phospholamban proteins involved in calcium movements, allowing an increase in contractility and relaxation [17].

Electrocardiographic data

Regarding ECG changes, all study participants presented at least one ECG change during the two ECG recordings conducted in 2022 and 2023. Training-related ECG changes are thought to require 4 - 8 hours of intense training per week in young athletes [2]. However, sinus bradycardia was the most frequent ECG adaptation among athletes, with 69% of cases in 2022. This is in agreement with the data described in the literature, considering sinus bradycardia as the most well-known electrical peculiarity induced by endurance training [18]. In 2023, a significant increase in the frequency of bradycardia was noted, justifying the effect of the parasympathetic system induced by chronic physical training. Bradycardia reflects the individual response of the athlete to intense training, without indicating a high level of performance [19]. It is correlated with the level of training [20] and the sport practiced (endurance or resistance sport) [19]. However, the duration of training also remains involved in view of the results obtained, with 75% sinus bradycardia noted one year later.

Comparative analysis of the frequencies of other objectified ECG features showed a significant increase in the frequency of left atrial enlargement (LAE) and biventricular hypertrophy (BVH), the percentages of which increased respectively from 2022 to 2023; from 6.25% to 44% and from 13% to 38% ($p = 0.04$ and $p < 0.0001$). The prevalence of LVH in our series was 75% in 2022, higher than the respective rates of 26.8% and 36.3% reported by Wilson *et al*. [21] and Ondze *et al*. [22] but relatively lower than those found in the series of Ba *et al*. [23] and Di Paolo *et al*. [24] which were 85.44% and 89%. These differences are certainly related to the criteria used to define electrical LVH in athletes. Indeed, the Sokolow-Lyon criterion, being the most commonly used, tends to increase the frequency of electrical LVH in athletes, unlike other criteria often used by certain authors [25].

The decrease in the percentage of isolated LVH from 75% in 2022 to 50% in 2023 is explained by the significant increase in the proportions of BVH from 2022 to 2023. Common adaptations such as increased QRS voltage, sinus bradycardia, and early repolarization patterns are typically benign and reflect normal cardiac remodeling. However, more pronounced changes, particularly in athletes engaged in endurance sports, such as LVH, present a greater challenge. LVH, characterized by elevated QRS amplitude and T wave inversions, results from the heart's adaptive response to meet the heightened oxygen demands of skeletal muscles by increasing ventricular dimensions to maintain adequate cardiac output [26]. These results demonstrate the influence of the duration and regularity of physical training on the appearance and maintenance of these ECG changes, even if the latter are described as being correlated with the intensity of the exercise and reversible upon cessation of physical training [2]. The frequency of early repolarization syndrome (44%) found in this study is close to the percentage of 47% found in Tougouma *et al.* in Burkinabe athletes [25]. However, we did not find any correlation between anthropometric parameters and ECG data recorded in athletes. There is a longstanding practice of examining exceptional human athletes to better understand the physiology of exercise and performance. The athlete's heart is a powerful model of human cardiovascular adaptation, reflecting the dynamic interplay between structure, function, and molecular signaling in response to sustained physical training [27]. The nature of cardiac adaptations varies depending on the type of exercise performed. Sporting disciplines can be broadly categorized based on their hemodynamic demands into isotonic (dynamic) and isometric (static) exercise, although most involve a combination of both like basketball [28]. Mixed sports exhibit a combination of cardiovascular adaptations associated with endurance and strength training, though to a lesser extent than specialized sports. For instance, basketball players may not sustain prolonged exertion comparable to marathon runners nor generate the intense pressure loads seen in weightlifters. Nonetheless, ECG findings in football players frequently demonstrate increased QRS voltage, indicative of strength-related adaptations, alongside sinus bradycardia, reflecting endurance training effects [29]. Black athletes are 2.5 times more likely to present with ECG abnormalities compared to white athletes, which are often misinterpreted as pathological. This increased prevalence of TWI in black athletes is typically a normal ethnic variant linked to the athlete's heart but can lead to unnecessary testing and interventions if not correctly identified. A more nuanced approach to ECG interpretation in these populations is critical to prevent over-investigation and reduce the associated clinical and financial burden [30].

Our study has some limitations, notably the small sample size, justified by the selection of a single basketball center whose administrators were in favor of monitoring the players for one year, representing the study period. The absence of cardiac ultrasound due to a lack of resources constitutes a second limitation, which would have allowed us to characterize the signs in favor of an athlete's heart in this young population. Among the genders, there were several salient findings. Most studies showed males as having higher QRS voltages, as well as longer QRS durations and higher PR intervals. In comparison, females had higher resting heart rates but longer QTc intervals. The incidence of abnormal ECG findings, however, was more often reported in males [11].

5. Conclusion

Endurance sports, such as basketball, induce significant physiological cardiac adaptations of a structural, functional, and electrical nature. The incidence and frequency of ECG changes observed in elite athletes are correlated with both the intensity of training and the length of time they have practiced the sport. Long-term, multicentric studies across diverse populations, including pediatric, adult, and veteran athletes, are essential to understanding the evolution of ECG changes.

Author Contributions

Conceptualization, MS Coly, M Fall, A Mbengue and FB Sar; methodology, MS Coly and M Fall; software, MS Coly, and M Diaw; validation, A Seck, A Samb, A Ba, A Mbengue and FB Sar; data collection, MS Coly and M Fall; formal analysis, MS Coly, M Diaw and AK Sow; investigation, MS Coly and M Fall; resources, MS Coly, SD Houndjo, M Toure, A Ba, AK Sow and M Diaw; data curation, MS Coly, M Fall and Mor Diaw; writing-original draft preparation, MS Coly, M Fall, M Diaw, A Ba, A Mbengue and FB Sar; writing-review and editing, MS Coly, M Fall, M Diaw, A Ba, A Mbengue and FB Sar; visualization, A Samb, A Ba, A Mbengue, and FB Sar; supervision, A Ba, A Mbengue and FB Sar. All authors have read and agreed to the published version of the manuscript.

Conflicts of Interest

The authors declare no conflicts of interest regarding the publication of this paper.

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