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Electrocardiographic findings in a group of physically active young adults who reside at 2,600 meters above the sea level: an exploratory study

Hallazgos electrocardiográficos en un grupo de adultos jóvenes físicamente activos que residen a 2,600 metros sobre el nivel del mar: un estudio exploratorio

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Abstract. Purpose: The physiological adaptations to regular physical activity and hypobaric hypoxia associated with high-altitude residence are related to a series of cardiovascular adaptations that can generate electrocardiographic modifications. This study aimed to describe the principal findings and determine the mean values of the electrocardiographic parameters in a group of physically active young adults who reside at 2600 meters above sea level. Methods: 49 young, physically active subjects (11 women) in a Sports Sciences program participated in the study. Each participant was subjected to a medical interview, a physical examination, and a resting electrocardiogram. Two physicians analyzed the electrocardiogram, searching for criteria of anatomical or physiological abnormalities; a descriptive analysis of the duration of waves and intervals and the amplitude of the P and T waves was also carried out. Results: The mean values of the electrocardiographic parameters were between the expected values. The principal findings involve sinus bradycardia and changes associated with the right side of the heart: incomplete right bundle branch block, right QRS axis deviation, and right ventricular hypertrophy. Conclusions: The findings of this study are related to other studies that describe changes in the right side of the heart in inhabitants of high altitude and sinus bradycardia in physically active subjects and, in some cases, in high-altitude residents. Every young dweller of the altitude who engages in physical activity should be submitted to a resting electrocardiogram, considering the high probability of finding changes in the electrocardiogram of asymptomatic patients that may require further exploration.
Keywords: Electrocardiogram, high altitude, hypoxia, exercise

Resumen. Propósito: Las adaptaciones fisiológicas a la actividad física regular y a la hipoxia hipobárica asociada con la residencia en la gran altura están relacionadas con una serie de adaptaciones cardiovasculares que pueden generar modificaciones electrocardiográficas. El objetivo de este estudio fue describir los principales hallazgos y determinar los valores medios de los parámetros electrocardiográficos en un grupo de adultos jóvenes físicamente activos que residen a 2600 metros sobre el nivel del mar. Métodos: 49 sujetos (11 mujeres) jóvenes físicamente activos pertenecientes a un programa de ciencias del deporte participaron en el estudio. Cada participante fue sometido a una entrevista médica, un examen físico y un electrocardiograma en reposo. Dos médicos analizaron los electrocardiogramas buscando criterios de alteraciones anatómicas o fisiológicas, también se realizó un análisis descriptivo de la duración de las ondas e intervalos y la amplitud de las ondas P y T. Resultados: Los valores medios de los parámetros electrocardiográficos se encontraron dentro de los valores esperados. Los principales hallazgos incluyen bradicardia sinusal y cambios asociados con el lado derecho del corazón: bloqueo incompleto de la rama derecha del haz de His, desviación a la derecha del eje del QRS e hipertrofia ventricular derecha. Conclusiones: Los hallazgos de este estudio están relacionados con otros estudios que describen cambios en el lado derecho del corazón en habitantes de la altura y bradicardia sinusal en sujetos físicamente activos y, en algunos casos, en residentes de la gran altura. Cada residente joven de la altura que realice actividad física debería ser sometido a un electrocardiograma en reposo, teniendo en cuenta que hay una alta probabilidad de encontrar cambios en el electrocardiograma en pacientes asintomáticos, que podrían requerir una exploración más profunda.
Palabras claves: Electrocardiograma, gran altura, hipoxia, ejercicio

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Introduction

It is thought that the first human beings arrived in America and the Andes Mountains in South America approximately twenty thousand years ago during the Pleistocene (Monge C & León-Velarde S, 2003). Since then, they have been exposed to a high-altitude environment. Among these mountains' most populated cities is Bogotá, Colombia's capital, located approximately 2,600 meters above sea level. Although there is no universal consensus for altitude classification, according to Pollard, Bogotá can be considered a city located at a high altitude (Pollard, 2003). Regardless of the altitude classification, the barometric pressure decreases as the altitude above sea level increases; this reduction in atmospheric pressure causes a reduction in the partial pressure of oxygen in the air, which generates environmental hypoxia (Burtscher et al., 2018). Due to the exposure to this hypobaric hypoxia ambient, humans develop a series of cardiovascular adaptations that involve changes in variables such as heart rate, stroke volume, and electrocardiographic parameters (Naeije, 2010). It has been described that the electrocardiographic parameters of the adolescents and adult dwellers of high altitudes are different from those who inhabit at sea level (Peñaloza et al., 1961). Electrocardiographic changes involving the right side of the heart, such as right QRS axis deviation and right ventricular hypertrophy signs, have been described in residents of high altitude (Parodi et al., 2023). These later findings may be associated with high-altitude pulmonary hypertension, which is secondary to the hypoxic pulmonary vasoconstriction, since the treatment with sildenafil, a phosphodiesterase five inhibitor, increases the concentration of nitric oxide and induces vasodilation, decreasing pulmonary artery pressure (Aldashev et al., 2005). Moreover, a moderate association between the probability of finding an abnormal ECG and the altitude has also been described (Aryal et al., 2017).

On the other hand, regular participation in physical activity generates electrophysiological changes in the heart that produce specific patterns in the electrocardiogram (ECG), such as sinus bradycardia and incomplete right bundle branch block (IRBBB), which can be considered normal findings in persons who regularly engage in physical exercise (Sharma et al., 2018). There has also been a description of electrocardiographic findings in athletes according to their level of physical fitness (Bjørnstad et al., 1993).

Since high altitude and exercise can independently influence different electrocardiographic parameters, it becomes necessary to analyze the effects that regular physical activity performed at altitude has on the ECG. Some studies have described the influence of altitude adaptation on the electrocardiographic parameters in children (Huicho & Niermeyer, 2007), adolescents and adults (Peñaloza et al., 1961). However, to the knowledge of the authors of this article, the same description has not been made in young, physically active adults who live in the altitude. Furthermore, most research regarding electrocardiographic findings in residents of high altitude dates from the twentieth century, and there are no reports on the physically active Colombian Andean population. This exploratory study aimed to describe the principal findings and determine the mean values of the electrocardiographic parameters in a group of physically active young adults who reside at a high altitude.

Methods

The participants of this study were a subgroup of patients from a more extensive study related to the angiotensin-converting enzyme gene polymorphism in athletes and physically active men and women. The study was approved by the research and ethics committees of the Universidad de Ciencias Aplicadas y Ambientales, and it was performed following the ethical standards described in the 1964 Helsinki Declaration and the resolution 8430 of 1993 of the Health Ministry of Colombia, which established the scientific, technical, and administrative norms for health research in the country. Prior to the collection of data, informed consent was obtained from all the participants. All the subjects were students at a university's Sports Sciences program in Bogotá, Colombia. As part of their formation, they regularly practised physical activity, which varies in intensity and frequency according to the semester in which they were. Therefore, they all were physically active. Moreover, most of them practice some physical exercise besides the one their career requires.

The subjects who underwent the resting electrocardiogram were selected by non-probabilistic sampling. They attended the university's physiology laboratory in the mornings, between 9:00 and 12:00. During the visit, the participants were subjected to a medical interview focused on their pathological background and their weekly physical activity routine, a physical examination measuring the vital signs, and a cardiovascular examination. Finally, ten electrodes were placed in the chest, arms, and legs while each patient remained supine at rest. A standard 12 lead electrocardiogram was obtained according to the Recommendations for the Standardization and Interpretation of the Electrocardiogram from the American Heart Association, the American College of Cardiology, and the Heart Rhythm Society (Kligfield et al., 2007). The electrocardiograph used for this measurement was a Schiller® Cardiovit MS-2010, in which the speed used for the register was 25 mm/s, and the sensitivity was 10 mm/mV. All the electrocardiographic files were stored in the device's memory; subsequently, they were downloaded in PDF format and printed for interpretation and analysis.

Two physicians analyzed the electrocardiograms in separate places and moments. One of these evaluators was a physician and physiologist with experience in cardiovascular and exercise physiology, and the other was a cardiologist. After analyzing the ECGs, they met to discuss the findings. The amplitude of the waves and duration of the intervals and waves were taken from the electrocardiograph measurements and then verified by the two evaluators. The criteria to determine electrocardiographic abnormalities were based on *Goldberger's Clinical Electrocardiography* (Goldberger et al., 2018) (Table 1).

The quantitative data were analyzed using Jamovi version 2.3 (The Jamovi Project, 2022). The quantitative variables were subjected to the Shapiro-Wilk Test to evaluate if the data were normally distributed. The median, mean, standard deviation, minimum, and maximum values were calculated.

Table 1.
Electrocardiographic parameters used to determine abnormalities

ECG abnormality	*Criteria
Left axis deviation	Axis of -30° or more negative
Right axis deviation	Axis of +100° or more positive
Right atrial overload	P wave > 0.25 mV
Left atrial overload	P wave with a duration > 120 ms
Right ventricular hypertrophy	R wave > S wave in V1, right axis deviation and negative T wave in right to mid-precordial leads
Left ventricular hypertrophy	Amplitude of the S in V1 + amplitude of R in V5 or V6 >3.5mV
Right bundle branch block	rSR' complex in V1 and qRS complex in V6 (duration ≥120 ms in complete block and between 110 and 120 ms in the incomplete block)
Left bundle branch block	QS complex in V1 and R wave without q in V6 (duration ≥120 ms in complete block and between 100 and 120 ms in the incomplete block)
Left anterior fascicular block	Mean QRS axis of -45° or more, QRS duration <120 ms (DI and aVL with a qR complex and rS complexes in DII, DII and aVF)
Left posterior fascicular block	Mean QRS axis of +120° or more positive with a QRS duration <120 ms (rS complex in DI and aVL with qR complexes in DII, DIII and aVF)

*Based on Goldberger et al. 2018.

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Results

A total of 49 young, physically active adults were evaluated, 11 women and 38 men, between the ages of 17 and 41. The other quantitative data recollected during the medical interview and physical examination, which included weight, height, body mass index, frequency of exercise, duration of the exercise sessions, systolic blood pressure, diastolic blood pressure, and arterial oxygen saturation, are shown in Table 2. According to the Shapiro-Wilk test, the age, the arterial oxygen saturation, the frequency, and the duration of physical activity did not have a normal distribution. All the subjects had a normal cardiovascular physical examination and did not report any pathological cardiovascular history or cardiac-related symptoms during physical activity.

Table 2.
Physical examination and physical activity data

	Age (years)	Weight (Kg)	Height (m)	BMI (Kg/m2)	SO2 (%)	SBP (mmHg)	DBP (mmHg)	*Physical exercise (days/week)	Duration of each training session (hours)
Mean	21.7	67.0	1.70	23.2	93.4	118	71.4	4.00	1.55
Median	21	67.0	1.71	22.6	94	117	72	4	1.50
Standard deviation	3.50	10.3	0.0901	2.58	1.26	9.66	7.75	1.84	0.752
Minimum	17	44.0	1.48	18.8	90	101	51	0	0.00
Maximum	41	90.5	1.91	31.5	96	140	88	7	3.00
Shapiro-Wilk p value	< .001	.710	.050	.141	.005	.151	.269	.026	< .001

BMI: Body mass index; SO2: Arterial oxygen saturation; SBP: Systolic blood pressure; DBP: diastolic blood pressure.
* Physical exercise is the regular physical activity performed by individuals to maintain their physical fitness, which was carried out besides the activity demanded by their sport sciences careers.

Forty-six (93.9%) individuals were born and lived in cities or towns located above 2500 meters above sea level; thus, most of the subjects can be considered native residents of the altitude. Three individuals (6.1%) were born in cities below 2500 meters but had lived in Bogotá for at least one year. We considered that all the subjects were physically active as they made regular physical activity for their formation as professionals in sports sciences. Moreover, 95.9% of them perform physical exercise besides the one their career demands.

Twenty-five subjects (51%) had a sinus rhythm in the ECG, with a 1:1 relation in atrioventricular conduction, a heart rate between 60 and 100 beats per minute, a PQ interval between 0.12s and 0.20s, and positive P waves in the bipolar leads. Since all the subjects performed regular physical activity, the following were considered normal findings in the electrocardiogram: sinus bradycardia (a heart rate <60 beats/minute but with all the other characteristics of the sinus rhythm) or sinus arrhythmia (defined as a change in contiguous RR intervals, greater than 0,12s but maintaining a regular pattern of the RR intervals), as these are the consequence of cardiac adaptation to exercise (Sharma et al., 2018). Sinus rhythm with a normal QRS axis (QRS axis between -30° and 110°) and no disturbances in atrial or ventricular conduction was also considered a normal finding. Twenty volunteers had an ECG with sinus bradycardia (40.8%), with heart rates between 41 and 55 beats/minute. Of the subjects with sinus bradycardia, seven (35%) did not have other associated findings, and 13 (65%) had other findings, which included right axis deviation, undefined axis, sinus arrhythmia, and IRBBB. A total of 4 subjects (8.2%) had sinus arrhythmia.

Table 3 shows the heart rate, the duration and amplitudes of the P wave, the amplitude of the T wave, and the duration of the PQ, RR, QT, and QTc intervals. According to the Shapiro-Wilk test, the heart rate was the only parameter with a nonnormal distribution.

Table 3.
Electrocardiographic quantitative data

	HR (beats/min)	P wave duration (ms)	P wave amplitude (mV)	T wave amplitude (mV)	PQ interval (ms)	RR interval (ms)	QT interval (ms)	*QTc interval (ms)
Mean	62.7	101	0.117	0.401	158	989	392	399
Median	62.1	102	0.110	0.390	156	966	394	402
Standard deviation	12.1	15.7	0.0422	0.111	20.7	174	30.9	22.5
Minimum	41.2	60	0.0300	0.170	120	555	316	347
Maximum	108	138	0.230	0.720	200	1456	496	457
Shapiro-Wilk p value	.001	.199	.422	.895	.191	.707	.051	.306

HR: heart rate; QTc: QT corrected.
*QTc Interval was calculated using the Bazett equation.

Fourteen (28.6%) subjects had an IRBBB, eight (16.3%) had right QRS axis deviation, seven (14.3%) met the criteria for right ventricular hypertrophy, four (8.2%) had a low progression of the R wave in the precordial leads, three (6.1%) had a P wave with an amplitude greater than 0.25 mV, one (2%) had a P wave with a duration greater than 0.1 s. Two participants (4.1%) met the criteria for left ventricular hypertrophy. None of the participants had isolated ectopic beats in their electrocardiograms.

Seven participants of this study (14.3%) reported a pathological background during the interview, and more than half of them had allergic rhinitis. One patient had type 2 diabetes, one patient had hypothyroidism, one patient reported hospitalization for arterial thrombosis of unknown origin, and four patients reported allergic rhinitis, which was treated occasionally with loratadine.

Discussion

This study found that the altitude's young, physically active residents had findings in the electrocardiogram that have been described as adaptations to both physical exercise and high altitude. These findings can be divided into sinus bradycardia and changes related to the right side of the heart. Among the latter, we found IRBBB, right axis deviation, and findings related to right ventricular hypertrophy. Since the middle of the 20th century, there has been a description of the electrocardiographic findings of the residents of high altitudes, such as right ventricular hypertrophy and complete and incomplete right bundle-branch block (Rotta & López, 1959), which are similar to the ones found in this study; however, in contrast to the present study, the level of physical activity of the participants of the other electrocardiographic studies in high altitude was usually not established. The present study's participants could be considered a particular group of university students since they belong to a sports science program. Therefore, they perform physical activity routinely. In this regard, the physical activity level of these students might be higher than that of university students. Pinillos-Patiño et al. found that 28.7% of students in a Colombian university never engage in vigorous physical activity, and 21.5% never engage in moderate or mild physical activity (Pinillos-Patiño et al., 2022).

The most frequent finding in this study was sinus bradycardia, which was present in 40.8% of the sample. Sinus bradycardia has been a frequent finding in athletes of different age groups, ranging from junior athletes (Sharma et al., 1999) to older ones (Jensen-Urstad et al., 1998). Some studies indicate that the aetiology of the sinus bradycardia associated with training is intrinsic electrophysiological changes of the sinus node (downregulation of the funny channel HCN4) rather than changes in the autonomic modulation of the heart (D'souza et al., 2014). Furthermore, heart rates as low as 45 beats per minute have been found in altitude dwellers since the first half of the twentieth century (Rotta, 1947). However, Horii et al. describe an increase in heart rate related to high altitude exposure (Horii et al., 1987), which can be generated by the increase in sympathetic activity that is seen in lowlanders acclimatized to high altitude and in native highlanders (Lundby et al., 2018). Since all the participants of the present study were young, physically active subjects, we propose that the finding of a low heart rate is more related to the adaptation of the sinus node to exercise rather than to the acclimatization to high altitude.

In the second category, we found changes related to the right side of the heart, including IRBBB, right axis deviation, and right ventricular hypertrophy. The most frequent finding in this category was the IRBBB which was present in 28.6% of the subjects. Rotta & Lopez found a frequency of right bundle branch block of 30.8% in highlanders of Morococha, Peru (4540 m). Of these individuals, 94.6% had an IRBBB, and the remaining (5.4%) had a complete right bundle branch block (Rotta & López, 1959). The prevalence of these findings is similar to that of this study, with the difference that we did not find a complete right bundle branch block in any of the participants. Right bundle branch block has also been described in athletes who performed a mean of 5,1 hours a week of exercise eight weeks before the ECG. In this group of athletes, the frequency of complete right bundle branch block was 3%, and of incomplete right bundle branch block was 9% (Kim et al., 2011). The frequency and intensity of this physical exercise are similar to the one registered in the present study. More studies need to be conducted to clarify whether the incomplete right bundle branch block is associated with exercise or with altitude in this particular group of subjects.

The other finding of the right side of the heart was right ventricular hypertrophy, with a frequency of 14.3%. Halperin et al. reported that electrocardiographic findings related to right ventricular hypertrophy were more frequent in men who had migrated to the altitude as a child or in patients with chronic mountain sickness than in native Tibetan residents (Halperin et al., 1998). In the present study, 85.7% of the subjects with right ventricular hypertrophy were native altitude residents. Only one subject (14.3%) was born in a city approximately 850 meters above sea level. This finding differs from the one described by Halperin et al., which is probably related to the genetic differences between the Tibetan and the Andean populations.

In the present study, 16.3% of the subjects had right QRS axis deviation. This finding has also been described in high-altitude dwellers. For example, Peñaloza et al. reported a statistically significant difference in the QRS axis between sea level residents and the dwellers of Morococha, Peru, a city located 4540 m above sea level. The latter showed a right QRS axis deviation in subjects aged 15 to 60. The mean values of the QRS axis of sea level residents were at 55° or lower for all the age groups, while for the dwellers of high altitude were at 105° or greater for all the age groups, although there was a wide range of QRS axis especially as the age increased (Peñaloza et al., 1961). This observation is related to the one made by Raynaud et al., who found that the dwellers of high altitude, living at 3800 m and 4780 m, had a mean QRS axis that was shifted to the right in comparison to the same axis in residents of the sea level. Moreover, the deviation to the right was even greater as the place of residence increased (Raynaud et al., 1981).

These findings could be related to the hypoxic pulmonary vasoconstriction response present during exposure to high altitude (West, 2012), which can cause an overload of the right side of the heart. Right QRS axis deviation has been described as the most frequent finding in Nepal dwellers of altitudes greater than 2800 meters (Aryal et al., 2017).

The present study used the QTc interval as the main parameter to analyze myocardial repolarization, and its mean value was between the expected range. The studies that have focused on the changes in myocardial repolarization parameters associated with altitude have made different and even opposite descriptions. Guntekin et al. found that there were no differences in heart rate and QT interval-related variables such as the QTc minimum, QTc maximum, and the QTC dispersion (difference between the maximum and the minimum QTc measured in different leads) among residents of the sea level and residents of a moderate altitude (1700 – 1800 meters above sea level). They only describe significant differences in the mean P wave minimum duration values, which were lower for the altitude residents (Guntekin et al., 2008). However, Akcay found that altitude could modify the heart's repolarization; a statistically significant increase in repolarization parameters, such as the interval from the peak to the end of the T wave (Tp-e), the Tp-e/QT interval ratio, and the QTc interval, was found in residents of moderate altitude (1600 m) compared to those who live at sea level (Akcay, 2018).

We hypothesize that a possible mechanism for some of the electrocardiographic changes associated with the hypoxic environment of high altitude could be related to the modifications in the activity of the autonomic nervous system, which is usually determined through heart rate variability (HRV) since a recent study found differences in time domain parameters of HRV in healthy males and females before and after the exposure to normobaric hypoxia (Rochel Vera et al., 2024). However, different autonomic responses may be present depending on the subject. Acclimatized lowlanders to high-altitude may have sympathetic dominance with reduced parasympathetic response compared to high-altitude natives (Dhar et al., 2018).

A resting ECG should be made in every young resident of the high altitude who wishes to engage in regular physical activity, considering that according to this exploratory study, there is a considerable probability of finding changes outside the expected sinus rhythm. This proposal is related to a European consensus for the pre-participation cardiovascular screening of young competitive athletes; this screening includes a personal and family history, physical examination, and a 12-lead electrocardiogram (Corrado et al., 2005). We recommend conducting probabilistic studies with a greater sample size and complementing the ECG with echocardiography since the ECG has a low sensitivity for diagnosing anatomical changes of the ventricles, such as right ventricular hypertrophy (Whitman et al., 2014). A study comparing sedentary and physically active inhabitants of the altitude should be done to confirm which of the changes found in this study are related to altitude adaptation and which are related to physical exercise adaptation.

Limitations

This study used electrocardiographic parameters searching for anatomic abnormalities of the heart, like right ventricular hypertrophy; however, Whitman et al. reported that the criteria for right ventricular hypertrophy in multiethnic adults had a low sensitivity and a low positive predictive value and consequently were not recommended as a screening tool (Whitman et al., 2014). Therefore, another type of examination, like echocardiography, should be used to assess the anatomical changes of the heart. As the present study had an exploratory scope, the sample size was small; thus, the results can only be applied to some of the high-altitude residents in the Andes Mountains of Latin America.

Conclusion

The major findings of this study in the physically active dwellers of the altitude were sinus bradycardia and changes dealing with the right side of the heart. These findings align with other studies that describe similar changes in the right side of the heart in inhabitants of high altitude and sinus bradycardia in physically active subjects and, in some cases, in residents of high altitude. The combinatory effects of exercise and altitude adaptation can explain the study participants' findings. However, more studies need to be done to establish which changes are related to physical exercise adaptation and which others are more related to high altitude. An electrocardiogram should be done in young, healthy adults who engage in regular physical activity, regardless of cardiac-related symptoms.

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