Electrocardiographic Patterns in Man at High Altitudes

By Andrés Rotta, M.D., and Andrés López, M.D.

Electrocardiograms of healthy men both native and long-term residents at 14,900 feet above sea level have been obtained and classified according to their dominant pattern. Most of the tracings showed signs of either right ventricular hypertrophy or right bundle-branch block, incomplete and complete. Some of the mechanisms responsible for these electrocardiographic changes found at high altitudes, such as pulmonary hypertension, positional changes of the heart, and chronic hypoxia, are discussed.

The effect of chronic hypoxia due to altitude on the right side of the heart is of particular interest. Measurements made on telerontgenograms of the heart of normal subjects living permanently at an altitude of 14,900 feet have shown an increase in the transverse diameter of the heart and in the cardiac silhouette area, as well as a prominent pulmonary contour. Complementary fluoroscopic studies have demonstrated that an increase in the volume of the right cavities rather than a total involvement is responsible for heart enlargement. More recently, by means of cardiac catheterization, a moderate but significant increase of the pulmonary artery pressure and of total pulmonary resistance has been found in men at high altitudes. Finally, a variable grade of right ventricular hypertrophy has been found in a small number of postmortem observations on subjects at high altitudes dying from work accidents.

The preceding information, as well as preliminary electrocardiographic observations carried out at this same altitude, at lower altitudes, and on miners without pulmonary silicosis from various altitudes and studied at sea level after several days of residence suggests that normal men living at high altitudes must show some electrocardiographic signs of right ventricular hypertrophy. The work reported here was designed to shed some light on this problem. Accordingly, electrocardiograms of a group of normal subjects residing at high altitudes were taken and compared with normal standards at sea level.

Material and Methods

One hundred and twenty electrocardiograms of healthy men, 20 to 54 years of age, and residents of Morococha (Peru), at 14,900 feet above sea level, were studied. Of the 120 tracings, 106 were of native Indians and 14 of white or mixed race born at sea level but having lived 15 to 30 years at high altitudes. Clinical examinations including x-rays and systemic arterial blood pressure were made in order to eliminate all possibility of respiratory or cardiovascular disorder. In some cases the arterial oxyhemoglobin per cent, blood volume, blood red cell count, and blood hemoglobin concentration were determined. In 7 cases with typical electrocardiographic patterns, right heart catheterization was performed following the method of Courmand and Ranges. The results obtained by heart catheterization have been reported in detail in a previous publication.

Electrocardiograms were taken during rest in the supine position, with Sanborn Viso-Cardiette and Cambridge Simple-Trol electrocardiographs. The standard leads, 3 augmented unipolar limb leads, and 7 unipolar precordial leads from RV_3 to V_6 were recorded. In 18 instances RV_3 was not registered; in 5 cases, the VE lead was recorded instead of RV_3, and in 6 additional cases leads from right precordium (RV_4, RV_5, and RV_6) were taken. In all tracings height and duration of the P, R, S, and T waves in standard and precordial leads were measured. The ventricular activation time (time of onset of the intrinsic deflection), from the beginning of QRS complex to the peak of R wave, was measured in V_1, V_5, and V_6. The mean electric axis of QRS and the R/S ratio in V_1, V_5, and V_6 were determined.

Results

A preliminary study of the electrocardiograms permitted us to divide the tracings into 4 principal groups according to their dominant pattern: (a) right ventricular hypertrophy, (b) suggestive of right ventricular hypertrophy (S_sR_sS_s pattern), (c) right hypertrophy,
bundle-branch block, incomplete and complete, and (d) normal.

A. Pattern of Right Ventricular Hypertrophy. In this group we have gathered all the tracings presenting a tall R wave, of 7 mm. or more, in RV₃, V₁, or both, with an R/S ratio greater than 1.0 in V₁ and less than 1.0 in V₅ or V₆.

Twenty-three electrocardiograms (19.2 per cent) showed a pattern that we have classified as right ventricular hypertrophy because they fulfilled several of the criteria followed by Sokolow and Lyon, Myers et al., and others in the diagnosis of right heart enlargement. Nineteen of these 23 cases were native Indians and 4 were subjects from sea level with long-term residence in Morocco. In Table 1 are outlined the right ventricular hypertrophy measurements obtained from this group. The P wave was found to be within normal limits in almost all cases and slightly exceeded 3 mm. in height in only 4 instances. The P-R interval ranged from 0.16 to 0.19 second and the QRS between 0.07 and 0.10 second. The height of R in VR was 5 mm. or more in 20 instances and was between 4 and 5 mm. in the remaining 3 cases. QRS in V₁ or RV₃ had a qR pattern in 11 cases, Rs or RS in 7, and rsR in the remainder of the 5 cases; this last pattern could be considered as incomplete right bundle-branch block associated with right ventricular hypertrophy. The electrical axis of QRS was found strongly deviated toward the right, between 110° and 170°, in 13 cases, and strongly deviated toward the left, between -110° and -172°, in 10 instances because these had the S₁S₂S₃ pattern in the standard leads. An increased depth of the S wave was found in the left precordial leads, and, as will be seen later, this is a frequent finding in the electrocardiogram of high altitudes regardless of the pattern of the tracing. The ventricular activation time ranged between 0.22 and 0.35 second in 11 cases, and between 0.35 and 0.45 second in the remaining 12.

In 4 instances T was found inverted in leads II and III, and in 9 cases in lead III only. In precordial leads, T was found in-

### Table 1.—Electrocardiographic Measurements in Twenty-Three Altitude Subjects with Pattern of Right Ventricular Hypertrophy

<table>
<thead>
<tr>
<th>Age (yr.)</th>
<th>Heart rate (bpm)</th>
<th>P-R interval (sec.)</th>
<th>QRS interval (sec.)</th>
<th>RV₃, Rs</th>
<th>RsR, RS, qR</th>
<th>RV₃, V₁, V₅, V₆</th>
<th>R/S ratio</th>
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ELECTROCARDIOGRAM AT HIGH ALTITUDES

verted 11 times in V_1, 5 times in V_1 and V_2, and once in V_1, V_2, and V_3. The Q-T interval was normal in all electrocardiograms.

Four typical records of this group are reproduced in figure 1. Tracing A was in a 34-year-old man who had arterial oxyhemoglobin of 80.5 per cent, a hemoglobin concentration of 20.2 Gm./100 ml., a mean pulmonary artery pressure of 25 mm. Hg, a pulmonary vascular resistance of 415 dynes/sec./cm.\(^{-5}\), and a cardiac index of 2.92 L./min./M.\(^2\). Tracing B was in a subject with 77.1 per cent of arterial oxyhemoglobin, and 20.5 Gm. per 100 ml. of hemoglobin; his mean pulmonary artery pressure was 28 mm. Hg; his pulmonary vascular resistance, 485 dynes/sec./cm.\(^{-5}\); and his cardiac index, 2.97 L./min./M.\(^2\). The electrocardiographic pattern we have described in this group corresponds to the classic pattern of right ventricular hypertrophy found in congenital heart diseases as well as in chronic cor pulmonale. When in these pathologic processes, however, an attempt has been made to correlate the electrocardiographic pattern with pulmonary hypertension, pulmonary resistance or work of the right ventricle, a tall R wave in V_1 with R/S ratio greater than unity have been observed to occur in most cases only if the mean pulmonary artery pressure\(^{16,17}\) is more than 30 mm. Hg, the total pulmonary resistance\(^{17,18}\) is more than 750 dynes/sec./cm.\(^{-5}\), or the work of the right ventricle\(^{19,20}\) is higher than 1 Kg./min./M.\(^2\). We did not obtain such high pressures or resistances in the 2 catheterized subjects. This observation suggests either that there must be other factors at high altitudes that contribute to the production of this type of electrocardiographic pattern or that the right ventricular hypertrophy may occur in the absence of marked increase of ventricular pressure, as has been found in cases of pulmonary stenosis.\(^{21}\)

B. Electrocardiographic Pattern Suggestive of Right Ventricular Hypertrophy. In this group we have considered all records that
presented main deflection downward directed in the standard leads with R less than 7 mm. in V₁ or RV₃ and R/S ratio less than 1.0 in V₁. Thirty-nine electrocardiograms (32.5 percent) showed these features. Seven of them were of long-term residents and the remainder of native Indians. All these records (table 2) showed a notable left axis deviation, from −80° to −172°, an R more than 5 mm. in height in VR₃, and a deep S in the precordial leads. The height of P was normal in all instances. In 34 cases the ventricular activation time in V₁ ranged between 0.012 and 0.035 second, and between 0.035 and 0.039 second in the remaining 5 cases. The QRS complex showed a duration of 0.07 to 0.09 second. The R/S ratio was greater than 1.0 in RV₃ in 11 subjects; in V₃ or V₆ it was less than 1.0 in 23 instances, and greater than 1.0 in the other 16. Inversion of T was found in lead III in 12 cases, and in V₁ in 18 subjects; inversion of T in V₂ or V₃ was not found in any of the records of this group in contrast to that seen in the previous group.

Five tracings of this group are reproduced in figure 2. Cases A and B represent the 2 subjects who were catheterized. Tracing A was in a 20-year-old native Indian of Moroco-
Fig. 2. Electrocardiograms with main deflection downward directed in the standard leads usually found at high altitudes. Cases A and B were catheterized.

cha whose arterial oxyhemoglobin was 81.3 per cent, and the blood hemoglobin 22.7 Gm./100 ml.; he showed a mean pulmonary artery pressure of 22 mm. Hg, a total pulmonary resistance of 292 dynes/sec./em.-5, and a cardiac index of 3.94 L./min./M.2

Tracing B was taken from a 27-year-old native Indian, in whom only the right ventricular pressure was obtained, with values of 29/3 mm. Hg for systolic and diastolic pressures.

Tracings with the main deflection directed downward in the standard leads have been rarely found at sea level, even in cases of cardiac or chronic pulmonary diseases.22-30 This has been interpreted as normal variant, as clockwise rotation of the heart on its long axis with the apex backward displaced, or as indicative of right ventricular hypertrophy, especially from the vectorecardiographic point of view.30 This same pattern has been found more frequently in cases of chronic cor pulmonale, congenital heart diseases, cardiac infarction, and rheumatic involvement of the mitral valve.30 In our study all these possibilities are excluded, since the tracings are of normal individuals. In 3 subjects who exhibited a typical S1S2S3 pattern in the standard leads with R/S ratio less than 1.0 in V1 and RV3, additional leads from the right precordium were taken (RV4, RV5, and RV6). In none of these cases did we find a tall R in such additional leads although the R/S ratio became greater than 1.0 in all the 3 cases. A tracing of this type is presented in figure 3, with additional leads of the right side. It can be observed that the R/S ratio was greater than 1 in RV5.

With more severe criteria, most if not all of the tracings in this group should be considered as representative of right ventricular hypertrophy. We have separated them in a different group, however, because of the very special characteristics they present, as can be seen in figures 2 and 3, and table 2. It is
important that approximately 1 out of 3 normal subjects living at a high altitude shows an electrocardiographic pattern of this type.

C. Pattern of Right Bundle-Branch Block Incomplete and Complete. Thirty-seven cases (30.8 per cent) of our series showed a RSR' pattern with a ventricular conduction time of more than 0.08 second. Following the criteria of Wilson and associates,31 and of Barker and Valencia,15 we have considered as incomplete right bundle-branch block the QRS interval ranging between 0.08 and 0.12 second, and as complete right bundle-branch block the QRS interval beyond 0.12 second. Of the 37 cases, 35 were classified as incomplete and 2 as complete right bundle-branch block. In none of the tracings was R higher than 10 mm. in V₁ or RV₅. In 16 instances QRS was W-shaped instead of M-shaped in right chest leads. In figure 4 are reproduced 3 electrocardio-

grams of this group. Tracings A and B were taken from 2 subjects who were catheterized. Tracing A was in a 22-year-old man whose arterial oxyhemoglobin was 79.4 per cent, and the blood hemoglobin content 19.2 Gm./100 ml.; the mean pulmonary artery pressure was 21 mm. Hg; the total pulmonary resistance, 294 dynes/sec./cm.²; and the cardiac index, 3.50 L./min./M.² Tracing B was in a subject in whom only the right ventricular pressure could be obtained; it was 42/6 mm. Hg. Tracing C was from a white man residing for 28 years in Morococha. It is important that incomplete and complete right bundle-branch block have been associated with pulmonary hypertension and with right ventricular hypertrophy in congenital heart diseases19, 20, 32-34 as well as with chronic cor pulmonale.14, 16, 17 It has been observed that the RSR' pattern in right precordial leads is most

![Figure 3](image1.png)

**Fig. 3.** Electrocardiogram with S₁S₂S₃ pattern at high altitudes in which additional precordial leads were taken. Observe that R/S ratio became higher than unit only in RV₅.

![Figure 4](image2.png)

**Fig. 4.** Incomplete right bundle-branch block in man at high altitudes. Cases A and B were catheterized.
frequently associated with low average systolic pressures, while a tall RV₁ pattern goes with high average systolic pressures.¹⁷

D. Normal Pattern. Twenty-one tracings (17.5 per cent) of all electrocardiograms obtained did not present substantial modifications in the configuration, amplitude, or direction of the inflections as compared to the normal standards established at sea level.³⁷, ³⁸ Nine of the 21 cases, however, showed a moderate right axis deviation, between 90° and 102°, and a deep S wave in left precordial leads even though the R/S ratio was higher than 1.0 in V₅ and V₆. Likewise, a somewhat tall R wave in VR was found in several cases although it did not reach 5 mm. in height. One subject of this group when catheterized had a right ventricular pressure of 32/4 mm. Hg.

Discussion

It is evident that the first 3 electrocardiographic patterns we have found in normal subjects living permanently at high altitudes are similar to cases of congenital heart diseases or chronic cor pulmonale associated with right ventricular hypertrophy found at sea level. Normal tracings should cause no surprise, since normal electrocardiograms have been found at sea level in cases of proved right ventricular hypertrophy.¹⁸, ³⁹, ⁴⁰ The mechanism for the production of right ventricular hypertrophy at high altitudes appears to be the increased pulmonary pressure that has been found at this altitude.⁶ However, as we have already mentioned, the electrocardiographic signs of right ventricular hypertrophy or right bundle-branch block in congenital heart diseases and in chronic cor pulmonale rarely appear at the levels of pressure or resistance that we have found in our catheterized cases. This suggests that the electrocardiogram at high altitudes is very expressive in detecting right ventricular hypertrophy and leads us to discuss some aspects of the problem.

First we shall dwell on the possible role that the positional changes of the heart plays in the pathogenesis and prevalence of the negative deflections of QRS complex in the standard and precordial leads. The changes in the position of the heart at high altitudes may be conditioned (a) by the broadening of the thorax with an elevation in the diaphragm, (b) by increased minute ventilation, higher vital capacity, and increased residual air,⁴¹ and (c) by an increased amount of pulmonary blood volume.⁴² All these mechanisms of respiratory adaptation may contribute in determining a clockwise rotation of the heart on its long axis and backward displacement of the apex. These changes in turn would be responsible for the predominantly downwardly directed QRS complexes in all 3 standard leads, giving rise to one of the most important characteristics of the electrocardiogram at high altitudes.

Another possibility to consider in the interpretation of the exaggerated changes in the electrocardiogram at high altitudes might be the existence of a slight degree of left ventricular hypoplasia which would enhance the electrocardiographic signs of the right side. We have no direct data based on autopsy material to settle this point, but it has been proved that at high altitudes the cardiac output is normal while the systemic arterial pressure is low, as compared to that found at sea level,⁴, ⁴³ with a resultant diminution of work for the left ventricle at high altitudes.

A third possibility to consider is the permanent exposure to anoxic environment throughout all or most of life. Apparently this would be an important factor in the development of the right ventricular hypertrophy at high altitude, since it has been demonstrated that electrocardiographic patterns of subjects from sea level taken to high altitude and left there for up to 1 year do not show the characteristics seen in those of native Indians or long-term residents.⁴⁴

The role of anoxia itself as a primary mechanism in the pathogenesis of the electrocardiographic patterns cannot be seriously considered, since anoxia acting as a general mechanism could produce biventricular hypertrophy of the heart with the concomitant electrocardiographic changes.

Finally, since the different patterns described in this study have been found in na-
tive Indians as well as in non-Indians living for a long time at high altitudes, we exclude race as well as any special process of natural acclimatization of subjects born at high altitudes as factors in the production of electrocardiographic changes.

**Summary**

Of 120 electrocardiograms of healthy adult subjects, natives or long-term residents of Morrococha, Peru (14,900 feet above sea level), 23 (19.2 per cent) presented definite characteristic signs of right ventricular hypertrophy, 39 (32.5 per cent) showed highly suggestive signs of right ventricular hypertrophy, 37 (30.8 per cent) were classified as right bundle-branch block (2 cases as complete and 35 as incomplete), and 21 (17.5 per cent) were within normal limits.

In most of the electrocardiograms a predominance of negative deflections in the QRS complex was observed in the standard as well as in the precordial leads regardless of the dominant pattern. This finding gives the electrocardiogram at high altitude a special characteristic that is not usually seen at sea level. The mechanisms involved in this phenomenon are discussed with special reference to the positional changes of the heart.

The electrocardiogram confirms the anatomic and radiographic findings of right ventricular hypertrophy previously obtained in normal individuals at high altitude. It is believed that the right ventricular hypertrophy is related to the pulmonary hypertension that is usually found in man at high altitudes.

**SUMMARIO IN INTERLINGUA**

Inter 120 electrocardiogrammas ab normal adulti, nativos o residentes permanente de Morrococha in Peru (4,500 m supra le nivello del mar), 23 (o 19,2 pro cento) presentava definitemente signos caracteristic de hypertrophia dextero-ventricular, 39 (o 32,5 pro cento) mostrava signos multo suspecte de hypertrophia dextero-ventricular, 37 (o 30,8 pro cento) eseva classificate como cases de bloco de branca dextere (2 complete e 35 incomplete), e 21 (o 17,5 pro cento) eseva intra le limites del norma.

In le majoritate del electrocardiogrammas un predominantia de deflexiones negative in le complexo QRS eseva observate in le derivations standard e etiam in le derivations precordial, sin reguardo al typo predominante del configuration. Iste constatation attribue al electrocardiogramma de grande altitudes un caracteristica special que non es incontrate usualmente al nivello del mar. Le mechanisms responsa bile pro iste phenomeno es discutite, con referentias special al alteration del position del corde.

Le electrocardiogramma confirm a constatation anatomic e radiographie de hypertrophia dextero-ventricular previamente reportate pro individuos normal a grande altitudes. Es opinate que iste hypertrophia dextero-ventricular es relationate al hypertension pulmonar que es usualmente observate in homines a grande altitudes.

**REFERENCES**


Five patients with ostium primum defects are presented in order to outline a distinctive clinical syndrome that should allow preoperative diagnosis. Unlike ostium secundum defects, patients with ostium primum defects frequently have difficulty in childhood. Prominence of the left chest is a manifestation of the early enlargement of the heart. Cyanosis and clubbing are occasionally present. The parasternal systolic murmurs are variable and may be absent. Ostium primum defect may be suspected if the murmur is loud, associated with a thrill, and located higher than the usual murmur of interventricular septal defect. A separate systolic murmur at the apex, recorded in all these patients, is 1 of the auscultation features by which this defect is suspected. Also significant is an apical first sound less intense than the second. Left ventricular hypertrophy may be present. The electrocardiogram usually reveals incomplete right bundle-branch block but may show right ventricular hypertrophy. The P-R interval is prolonged. Fluoroscopy reveals right and left ventricular hypertrophy and increased pulmonary flow. Catheterization demonstrates a large left-to-right shunt. The majority of the criteria for separation from the more common atrial septal defects depends on the presence of either a cleft mitral leaflet or an incompetent common atrioventricular valve.

KURLAND
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