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LIFE IN THE ANDES AND CHRONIC MOUNTAIN SICKNESS

By Dr. CARLOS MONGE

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SINCE prehistoric times congenital or acquired acclimatization has made life possible upon the high plateaus of the Andes, where the altitude varies from 10,000 to 16,000 feet. At the present time twelve million people are living on these plateaus under normal conditions, at an oxygen pressure of about 85 mm instead of 150 mm as at sea-level. In considering the steady biological changes produced by ancestral acclimatization to chronic oxygen insufficiency we must assume that dwellers in these highlands belong to a climatophysiological variety of the human race, which, as observation shows, may even be responsible for their individual attitudes and sociological behavior. Anthropological morphology does not suffice to explain life in the Andes—the fundamental basis must be found in the physiological dynamics of altitude homeostasis. If we go back to Galen we will remember that "the organism is a whole with an environment and it can not be considered apart from that environment" (Hutchins), a fact not yet established in the natural history of men in the Andes.

The claim to acclimatization acquired after a few days or weeks, "a fallacy of misplaced concreteness," misinterprets the nature of the problem and has pro-

duced much confusion. Acclimatization connotes a balanced state of the internal milieu; therefore, at high altitudes body and mind must attain the same equilibrium that man has at sea-level. To arrive at this, to overcome the otherwise impaired condition caused by chronic oxygen insufficiency, the organism calls forth its emergency adaptative devices and builds up a new chain of biological processes to stabilize its internal environment. Thus it first has to be adapted. Adaptation is in itself a malady, slow in course, generally following an acute stage—the so-called acute mountain sickness—which may be without clinical symptoms or with only mild symptoms or with the outstanding symptomatology of chronic mountain sickness. Whether the adaptative period lasts months or years, nobody knows. Probably it depends on the ability of the individual to compensate the damage caused by the permanent effects of the lack of oxygen. This is a personal equation. There are men and animals with remarkable powers of acclimatization; there are others, on the contrary, who never achieve that goal.

When the adaptation malady is over, acclimatization supervenes: so-called chronic mountain sickness has been cured.

The Native Andean and the Adapted Man. It would obviously be pretentious to try to discuss all the biological characteristics of the Andean man, whose study is only just beginning. In both the native Andean and the adapted man you will find an increase in the number of red blood cells and in hemoglobin capacity; in size of the erythrocytes (Hurtado, Talbot); in the viscosity of the blood; in resistance to hemolysis; of hematocrit; of serum proteins (Monge-Salas); of pH, but within normal limits; in the ventilation of the lungs; and in hypertonus of the vegetative nervous system (Monge, Pesce, Aste, Salazar). There will be a decrease in arterial oxygen saturation, in carbon dioxide alveolar pressure and in alkaline reserve.

And now let us consider some of these characteristics which may differentiate the adapted from the acclimatized dweller of the highlands. Talbot emphasizes the fact that the maximum oxygen capacity of some of the adapted men of the International Expedition of 1935 never reached the lower limit of dwellers acclimatized at 5.3 km altitude. Keys, Hall and Guzmán-Barrón stated that hemoglobin has less affinity for oxygen in newcomers to the highlands than in residents, that this probably accounts for the shift to the right of the oxygen dissociation curve at high altitude, and that it may be an intermediate stage in final adaptation. In regard to the alkaline reserve, Dill, Talbot and Consolazio stated that the adapted man never reaches the lower values of the acclimatized person.

Hurtado in 1932 found an increase in the mid-capacity of the lungs, a true physiological emphysema and augmented vital capacity. On the basis of animal experimentation, he believes that the dilated pulmonary capillary affords a larger contact surface for the diffusion of gases. Mori-Chavez and I, in 1934, demonstrated in guinea pigs that the hyperplasia of the capillary bed and diminished connective arteriolar structure are conditions of an acclimatized lung.

Besides the biological features, some peculiar physiological characteristics are to be observed in the Andean man. According to Rotta (1938) the cardiac index is moderately increased, the work of the heart is 20 per cent. higher, and the volume of blood is augmented. The transverse and longitudinal diameters of the heart are somewhat greater than that of the sea-level heart. The venous pressure is slightly increased. We reported in 1930–1935 that 13 per cent. of the men tested showed a heart rate of less than 50 pulsations per minute, and 41 per cent. a rate of less than 60 pulsations. But between work and heart rate there is no linear relation. After double the amount of work—1,400 kilogrammeters—the pulse is slower than for a basic work of 700 kilogrammeters. Of 300 normal and selected men, 27 per cent. showed practically no tachycardia after 700 kilogrammeters work, enduring the test without fatigue. Torres established the fact that arterial tension is lower at altitude than at sea-level. Thus there seem to be all the conditions of an athletic heart. Chronic oxygen insufficiency is a permanent stimulus to improve heart efficiency.

Clinical efficiency tests (Master test) show that half of the Andean men (300) are stronger than men at sea-level. The acclimatized man on the high plateaus climbs a mountain straight without difficulty. Adapted persons can never do that. For a moderate amount of physical work, a sea-level athlete in the highlands is in the same position as the untrained man at sea-level.

Grollman and Christensen have demonstrated that cardiac output during inactivity increases in the first few days of adaptation and then returns to normal. It is unfortunate that there is not available more information on acclimatized man. In the case of an adapted subject at work, Christensen found that the cardiac output and the capacity for oxygen transport were diminished. Theoretically, the cardiac output of the Andean should be considerable because of his slow heart beat and his capacity to carry on strenuous exercises.

In 50 per cent. of efficiency tests—with or without a brief tachycardia—the pulse becomes slower and then accelerates, reaching the initial normal rate. This paradoxical post-effort bradycardia, a fact never found in the physiology of the sea-level man,

has been electrocardiographically recorded (Monge-Sáenz). In addition, brief periods of inverted P wave and shortness of PR, varying activity of the pacemaker, inconstant partial block and deviation of ST have been found, during which test the subject felt no fatigue. This differs from what Greene and Gilbert (1921) found in aviators during extreme oxygen want. We can assume that during the bradycardia period the heart fibers stretch to the utmost in an unaccustomed way. Heart dilatation and sudden death sometimes ensue in mountain sickness.

On the other hand, in 8 per cent. of the acclimatized subjects we found tachycardias, which started suddenly without any clinical distress, alternating with slower rates. Efficiency tests during this phase do not interfere with the initial acceleration. The pulse goes up and down keeping to the basic tachycardia, but at any moment the rate may return to bradycardia. Probably there is a sudden change in the pace-maker, but electrocardiographic records appear normal.

There is hypertonus of the vegetative nervous system, as proven by oculo-cardiac, Danielopoulo atropine and solar reflex tests (Monge, Pesce, Aste), during which the Andeans do not feel any distress at all, but the adapted men, on the contrary, frequently collapse. This explains the heart features we have just described. The increased vagal tonus, due to anoxemia, as Greene and Gilbert proved in 1921, in animal experimentation, seems to cause the bradycardia, which may be considered a feature of the altitude heart. In adaptation, after a time the slower rate probably becomes an intrinsic function of the heart muscle. The parallel activity of the sympathetic adrenal system contributes to the same result. This may explain the tachycardia of sinus origin, which constitutes another paradox of the heart rate at high altitudes. This hypertonus of the vagal-sympathetic system must have some connection with stability of the vasomotor center and reflex nervous system. Gebhorn's findings on man (1937) give an interpretation to the collapsing form of mountain sickness.

In discussing acclimatization the buffer capacity of the body has not been stressed sufficiently. The adapted and the acclimatized man have practically a similar alkaline blood reserve, but their behavior is quite different. We observed in 1928–1935 that the shift of the pH after work of about 700 kilogrammeters at high altitude either equals or is less than the values attained at sea-level. On the other hand, in adapted persons the difference in ionic concentration is three times higher. This gives an idea of the stability of the internal environment already outlined. We have established the fact of loss of alkali in men during ascent (1928). There is a reciprocal relation between the blood alkaline wave and the elimination of bases through the urine, measured by pH, the ammonia and the titration acidity (Monge). This pH correlation between blood and urine has just been found by Brassfield and Behrmann in animal experimentation. The condition is reversed on returning to sea-level (Monge). This change must be compensated to attain a normal buffer capacity.

Very little is known about the biological processes of tissue oxygen fixation and of restoring the buffer systems. It is generally conceded that there is an interplay of chemical reactions between blood and tissues to keep the fixity of the internal milieu. At high altitude internal respiration must be conditioned by its capacity to fix oxygen and its power to buffer and to release carbon dioxide. Guzmán-Barrón, Dill, Edwards and Hurtado have suggested that there is a disturbance of the oxydation-reduction system. Hurtado found increased myoglobin. We pointed out in 1928 higher venous oxygen saturation in adapted than in acclimatized subjects. It appeared as though the tissues had not taken it from the blood. Aste-Salazar recently found facts to support this. High venous saturation may also be interpreted as an effort to maintain the capillary oxygen pressure. So we suggested, "Altitude changes the capacity of the tissues to fix ogyen. We can assume there are some unknown tissue reactions which bring about acclimatization" (1928). But this entire acclimatization hypothesis must also consider the production, buffer, transport and release of carbon dioxide.

May I suggest that the native or acclimatized highland dweller possesses some of the biological characteristics needed in an aviator, and that perhaps a better knowledge of the physiology of a man born at an altitude of 15,000 feet might contribute to an understanding of conditions of fitness required for high altitude flying?

Physiology of Reproduction. Sometimes the adapted person's body and mind seem to be in excellent condition, but, surprisingly, he may prove completely sterile. A study of the fertility of rams brought from sea-level revealed that only 50 per cent. are able to produce offspring the first year; after two or three years the highest reproductive average reaches only 70 per cent. Thus 30 per cent. sterility seems to result. Rams acclimatized since Colonial times, on the contrary, reproduce 100 per cent. Eggs brought up from sea-level do not always hatch in high altitudes.

Sterility in rabbits, cats, horses and cattle has also been found. We produced aspermatogenesis in rabbits and cats. The pathological picture resembles that of cryptorchidism. San Martin has found that some dilutors for artificial insemination do not work in high

altitudes, and this elucidates another altitude problem. If we consider these facts from an industrial point of view we can realize their importance because they affect the food supply and the economy of South American high plateaus. Similar disturbances sometimes occur in men who, though fertile at lower levels, prove sterile in the higher altitudes. History supports this observation. Father Calancha's writings (1639) describe the Spanish conquerors going to Potosí (14,000 feet) and having no offspring until fifty years after the city was founded. The mechanism, then, which enabled them to become acclimatized established itself slowly indeed. On the other hand, the average reproduction of the natives was 100 per cent. In 1639 the capital of Peru was transferred from Jauja (13,000 feet altitude) to Lima at sea-level because horses, fowl and pigs did not produce offspring at the higher altitude. Time does not permit me to give more examples.

But I do not want to create a wrong impression. The acclimatized population is always increasing. The average birth rate at 15,000 feet equals that of sea-level. We are convinced that there are both animals and plants with the superacclimatization power necessary to live on the high plateaus.

Sociological Behavior. The biological characteristics of men of the high plateaus mentioned are different from those of men at sea-level. That is why the men of the Andes may be considered as belonging to a climatophysiological variety of the human race. In fact, they are closely related to their geographical surroundings—altitude, radiation, humidity, ionization, and so on. The sociological behavior of such men and the telluric environment appear as one biological system which can not be divided, as a climatophysiological unit. So men must adapt themselves when they come down to the coast; they can not always stand the meteorological conditions of the lower lands; they become predisposed to disease of the lungs, as we have reported (1934). But the struggle for existence forces them to come down. Every year about one hundred thousand men come down to sea-level for agricultural work and then follows something worth noting: after about three months they go back to the altitudes; they never stay on the coast, no matter what it offers them. The reverse is true: if men go up to the mines, they soon return to sea-level. These peculiar annual migrations of high plateau societies are a well-known fact of biological significance. These persons are like migratory birds; they have the urge to return home. Thus, the Andean man has the same problems of acclimatization to face when going down to a land not always suited to his physiological equipment. I do not want to convey a wrong impression. Usually acclimatization on the coast is easier than in the highlands. But there are facts, the study of which is of the utmost importance to knowledge of the Andean population: these have to do with labor, assurance, migrations, army and health. With respect to these facts history is conclusive.

During the Inca period men of the high plateaus were allowed to colonize lands of the same climates only. When the highland peoples had to fight on the coast during the wars, they had two armies which they used alternatively, thus avoiding the climatic trauma of the lower lands (Garcilazo de la Vega, Padre Cobo). The Inca's sanitary legislation as well as that of the Colonial times recognized these facts and tried to codify them. The Republic is unaware of the problem, and that is why in a recent war (Bolivia-Paraguay) the climate of the tropical lowlands of central South America killed more people than the enemy's bullets. The lessons of history have been forgotten. The day will come when those vital matters will receive due consideration for the benefit of the human beings living in high altitudes. To this end we need education and research.

Chronic Mountain Sickness

From our point of view chronic mountain sickness means non-acclimatization, that is, impaired adaptation, and also loss of acclimatization. It may pass through a severe stage, so-called acute mountain sickness. To be born at high altitude does not confer immunity. Some of the features of this disease have already been outlined. We shall consider the severe forms of chronic mountain sickness only.

In regard to its symptomatology there is a perfectly characterized type which I have called erythremia of high altitude because it exactly resembles *polycythemia vera.* We must insist upon the fact that this disease is a clinical syndrome and not a hematological pattern. We can summarize it as follows:

At rest the patient appears reddish or blue, and he turns purple at the least effort. In cases of most severe involvement the scleras are intensely colored by the distended capillaries, the eyes being hidden behind edematous and bluish eyelids. The face is blue-violet, almost black, resembling that of an asphyxiated person. The mucous membranes are reddish. The tongue appears larger than normal and full of blood. All the superficial blood vessels appear dilated. Varices are common. Epistaxis is frequent; aphonia is usually noted. The hands show clubbing of the fingers. The nails become thick and appear to be inserted like watch glasses. The person resembles an old emphysematous, plethoric patient, walking slowly and heavily. He feels extremely weak and has a marked tendency to sleep. A state of drowsiness is

found frequently. Spells of dizziness and fainting occur commonly. Nausea and vomiting at the least effort are noted occasionally; there are spells of diarrhea. Blurring of vision and temporary blindness are frequently observed. Transitory deafness occurs. Sometimes the patient suddenly falls into a kind of asphyxial coma for two or three hours, to return later to his pitiful condition. Aphonia, coughing and repeated bronchitis are present. Also recurring are congestive processes in the lungs accompanied with hemoptysis.

As the disease progresses, cardiac insufficiency ensues. In some cases symptoms of angina pectoris appear after exertion. Collapse occurs often. Hypertension happens rarely. In only two out of seventeen cases was the size of the spleen moderately increased.

Patients complain of a variety of algesias. Some of them have excruciating pains in the lower extremities; others have constant pain in the lumbar region or in the joints, particularly in the tendon attachments at joint cavities. These pains may subside spontaneously or may cease if the patient descends to a lower altitude. There may be violent cephalagia, subsiding after lumbar puncture or bleeding. Bleeding improves the condition immediately in such cases. Paresthesias are varied in type and in localization. Some patients complain of unpleasant sensations of heat in the face; others, of violent sensations of cold. One said he felt as if warm water were being thrown on his back. One had the sensation of the loss of one hand; another complained of "bandaged legs." Formication and sensations of being pricked by pins are frequent. Those symptoms are similar to aeroembolism, as described by Armstrong.

Some persons are rather predisposed to congestive cerebral syndrome (Monge, 1936). This appears as a spasm of painful headache, sensation of fullness of the head, of hot flushes on the face, photophobia, injection of ocular mucosa and blurring of vision, scotoma, lacrimation, vertigo, dizziness, pain in the abdomen, general sweating and vomiting. The pulse becomes slower. Cyanosis is intense. These crises may last some minutes or several hours. When this occurs, the patient sinks into drowsiness which passes into unconsciousness. Frequently, an epistaxis releases the stuporous condition and the patient improves. The spinal fluid pressure is remarkably increased. In a recent case, Arellano found that the spinal fluid pressure surpassed the highest mark of the Claude manometer. Repeated lumbar puncture relieves the patient. This syndrome may be interpreted by considering the recent findings of Armstrong, Michelsen, Thompson and Maurer, who observed an increase of spinal fluid pressure in animals exposed to anoxia. Walsh and Boothby, in a low-pressure chamber, have seen bubbles appear in man and have noted increased spinal fluid accumulation. Arellano's case and our findings (1938) probably have the same explanation. Hemiplegia is not uncommon. After a sojourn of several years at 4.6 km one patient developed the symptomatology of moderated erythremia. Suddenly one day he developed a moderate degree of palsy of the right arm and aphasia. After a few minutes the disturbance disappeared. Every morning thereafter the trouble returned and the patient was obliged to come down to the capital. He showed some impaired mental and physical condition, but after a few days appeared normal. Two months later he returned to the mountains, but after three weeks the trouble reappeared. The last time he went up he developed deep psychic disturbances, a confused mental state and symptoms of acute soroche. He was brought to the coast against his will. A few days later he was entirely recovered, but he could not remember what had happened. He was obliged to give up his work in high altitudes.

In a recent case, after several years of erythremic symptoms the patient found himself unable to work and he had a fear of traveling. He worried much about this. He said it was "a silly idea" but he could not help it. He saw everything wrong; he was afraid of meeting his employees at the saw-mill. Sometimes he got up at night and went to work; he realized that there was nothing to do, but he went there just the same. Finally he felt like a "criminal" or a "murderer" and he conceived the idea of committing suicide. Then he came down to sea-level and was immediately relieved; the mental disturbances disappeared. When he returned to the highlands the idea of suicide persisted. Under the circumstances, we kept him in Lima, where he was completely normal. In cases of severe involvement there may be marked disturbances in the behavior and memory of the patients. An engineer had attacks of mental confusion during which he would make gross mistakes in arithmetic and drawing. Even with knowledge that descending to sea-level would effect a cure, he could not take the initiative to make the trip.

Nervous exhaustion is very common. The patients complain frequently of sexual frigidity. We have seen albuminuria vanish when patients were brought to sea-level and return as soon as they went back to high altitudes. We have found persons with a syndrome of recurrent collapse, hyperventilation and attacks of tetany, who entirely recovered when brought to a lower region. Similar condition has been found by Hinshan and Boothby in aviators. Marked polycythemia is the characteristic feature in these patients, the red blood cells being as a rule between 7,000,000

to 9,000,000 in number and of larger size than at sea-level. The number of reticulocytes is increased also. There is a slight leukocytosis and essinophilia. There is a predominance of monocytes. Alterations in the process of clotting are observed. One patient had bleeding of the gums, but this disappeared as he went down to a lower level. In another case the patient had convulsive attacks accompanied by pupura and the presence of blood in the cerebrospinal fluid, all of which disappeared when he was brought down to sea-level. The bilirubin is highly increased. The pH of the serum diminishes during asphyxial attacks, while after the crisis has passed, it goes up to 7.50–7.70 (Aste-Salazar[1]). The alkaline reserve of the plasma is greater than that of a person who is acclimatized to high altitude. The concentration of hemoglobin in the blood is considerably increased, in one case reaching 179 per cent. (taking 100 as the value found at sea-level). The viscosity of the blood is increased. There is high blood volume (Hurtado) and diminished plasma volume. The oxygen saturation of the arterial blood is considerably decreased. Hurtado found 57 per cent. in one case, and Aste from 70 to 80 per cent. High venous blood saturation reaches normal levels when the patients improve at sea-level. High basal metabolism is found in severe cases.

Evolution of the Disease. As a rule the patients consult a physician only after the illness has been present for some time, and it can last usually from two to twenty years. Sometimes a patient becomes temporarily well even while staying at a high altitude. Usually, after a stay at sea-level a patient returns to a high altitude and lives there for some time without great discomfort. As time goes on, however, the cure at sea-level is less and less enduring, and asphyxial disorders may occur as soon as the patient reaches a high altitude. These disorders may sometimes cause death.

From this condensed description it is seen that the fundamental characteristic of high altitude disease, the characteristic which has made us group it as a nosographic entity, is the fact that all the symptoms subside or disappear as soon as the patient is brought down to sea-level. This feature is undoubtedly due to a common cause, anoxemia. The predominance of any symptom must be due to the fact that the particular organ involved has suffered great damage from the prolonged effects of lack of oxygen.

Besides these severe forms of chronic mountain sickness there are cases of subacute evolution, with slight impairment of physical and psychical conditions and a mild erythremic symptomatology.

At times one can find some individualized forms: pulmonary, cardiac, renal, digestive, etc. But a skilful clinician can always differentiate an erythremic complex. Silicosis, however, frequently displays an exaggerated symptomatology of chronic mountain sickness.

In conclusion it may be said that we have found a climatophysiological variety of human being and a climatopathological variety of human disease. But our work represents only a tentative effort in fields of education and research that are still unexplored.

LOW TEMPERATURE PHYSICS IN THE USSR

By Professor C. T. LANE

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THE extraordinary performance of the Russians on the Eastern Front has been a surprise to many people in this country. We had supposed that most Soviet industry was badly managed and Russian technicians, as a whole, inept. Those of us, however, whose interest in certain scientific fields had compelled us to pay some attention to Russian research were, I think, agreed that much of this work was of a high order and comparable in quality with the best American and British effort. Generally speaking, any nation with a healthy interest in pure research is likely to have a vigorous industry, and *vice versa*.

In the special field of low temperature physics Russian contributions both in the pure and applied domain merit special attention. At least two excellently equipped laboratories for such studies have been built in the past ten years. The best known of these is the Institute for Physical Problems at Moscow under the direction of P. L. Kapitza, but excellent work has also been done at the Physico-technical Institute at Kharkov under W. Schubnikov. It is probably a fair statement of fact to say that Kapitza is the most distinguished of all present-day Soviet physicists. He first appeared in England during the twenties at Cambridge, and, with Rutherford's backing, had very soon perfected an apparatus for the production of magnetic fields some ten times more intense than anything previously attained. During the period 1926–1930 a considerable number of fundamental papers on the properties of metals in high fields appeared from Cambridge. About 1929 Kapitza's interest appears to have shifted to low temperature work, probably because he recognized that such studies

[1] Unpublished work.