

The Mexican Response to high Altitudes in the 1890s: The Case of a Physician and his “Magic Mountain”

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Introduction

Mexican science—and experimental medicine in particular—at the end of the nineteenth century is little studied by historians, although it is extremely rich and attractive. Current tendencies in the history of science make a sharp division between the science of developed countries and that of “developing” ones; referring to the latter as “peripheral” science,¹ as it is felt that it cannot be measured by the same parameters as the science that is carried out with greater resources and that contributes revolutionary knowledge. One possible reason might be the lack of knowledge of peripheral science, given that, from the late nineteenth century, science in its purest experimental and methodological² senses was indeed being done; science that did in fact make real contributions to knowledge, though they are all but unknown.

In this paper, we use modern criteria to analyse some of Dr Daniel Vergara Lope Escobar’s experimental results.³ For almost thirty years, this doctor studied the bodies of his compatriots with the main objective of proving that they were not inferior just because they lived on Mexico’s high plateau. According to European physiologists of the period, the low barometric pressure (585 mm Hg) and high elevation (2,240 metres above sea level) of the area meant that the inhabitants breathed a kind of “rarefied” air which was believed to have a lower oxygen concentration that caused physical lethargy and “cerebral” anaemia.⁴ When he began his research, Vergara Lope studied cardio-respiratory physiology, but he devoted the later years of his career mainly to the study of anthropometry.⁵ His intention was always the same, however: to prove that the Mexican race was not inferior because of the environment in which it lived.

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¹ M Cueto, *Excelencia científica en la periferia: actividades científicas e investigación biomédica en el Perú 1890–1950*, Lima, GRADE, 1989.

² A C Rodríguez de Romo, ‘Fisiología mexicana en el siglo XIX: La investigación’, *Asclepio*, 1997, 49: 133–45.

³ A C Rodríguez de Romo, ‘La fisiología de las alturas en el siglo XIX mexicano: Implicaciones médicas, científicas y sociales’, in *Archivo General de la Nación, Talleres Gráficos de México, México en el siglo XX*, México, Archivo General de la Nación, 1999, pp. 640–63.

⁴ D Jourdanet, *Les altitudes de l’Amérique Tropicale comparées au niveau des mers au point de vue de la constitution médicale*, Paris and London, J-B Baillière, 1861, pp. 65–6.

⁵ L Cházaro, ‘La fisioantropometría de la respiración en las alturas, un debate por la patria’, *Ciencias*, 2000–2001, 60–61: 37–43.

The originality of the study we present here consists of the following features: first, it is a modern interpretation of past events, still embedded in their historical context; second, it demonstrates the largely unknown work of an important Mexican scientist; third, it deals with the importance given to the influence of national context and personal motivation in the work of scientists; and, fourth, it includes a comparison of data on the respiratory functions of the nineteenth-century Mexican population with those of populations recently studied in moderate-altitude zones.

Background

Social and Scientific Environments in Mexico

In the way of all totalitarian regimes, the dictatorship of Porfirio Díaz (1830–1915) brought about economic, political and social problems. It must be recognized, however, that it also initiated a long period of peace that lasted almost thirty years and allowed the arts and sciences to flourish. In addition, President Díaz was convinced of the utility of science and had his own highly personal interpretation of positivism. He believed that those countries that encouraged scientific activities were “developed”,⁶ so his support of scientific research during this epoch was congruent with his project for the nation. Order and progress were fundamental for a people in search of an identity that needed to be validated medically.

During the *Porfiriato* (as the period of Porfirio Díaz’ dictatorship is commonly known), scientific activity took off, as scientists acquired new significance for the government. Institutes, academies and societies were created,⁷ and an impressive number of scientific journals began to be published. Physicians were very important in this process, because, in addition to their specifically medical activities, they were also botanists, zoologists, naturalists and philosophers.⁸ This was the context in which the physician Daniel Vergara Lope Escobar (1865–1938) grew and developed. He was a typical son of educated people in that generation and was schooled in that purest of positivisms implanted in Mexico by the physician Gabino Barreda (1818–81). Vergara Lope, a faithful admirer of Claude Bernard (1813–78) and follower of his precepts of experimental medicine, did his scientific work at the Instituto Médico Nacional (IMN, or National Institute of Medicine). Created on 7 December 1888 and suppressed on the same date in 1915, the IMN was nourished by a fervent nationalistic sentiment that studied the fauna, flora, climate and geography of Mexico.⁹ The Institute contained five sections and Vergara Lope belonged to the third—Experimental Physiology—where he set up his own laboratory. Although salaries for researchers were included in the Institute’s budget, scientists were assumed to work only a few hours a day; the Institute did not conceive of the modern figure of the full-time researcher. This makes Vergara Lope even more noteworthy, as, not only did he spend

⁶ A C Rodríguez de Romo, ‘La ciencia pasteuriana a través de la vacuna antirrábica; el caso mexicano’, *Dynamis*, 1996, 16: 291–316.

⁷ L F Azuela Bernal, *Tres sociedades científicas en el Porfiriato. Las disciplinas, las instituciones y las relaciones entre la ciencia y el poder*, México, SMHCYT-UNAM, U. Nezahualcóyotl, 1996.

⁸ A C Rodríguez de Romo, ‘Las ciencias naturales en el México Independiente; una visión de conjunto’, in H Aréchiga and C Beyer (eds), *Las ciencias naturales en México*, México, Fondo de Cultura Económica, 1999, pp. 93–128.

⁹ *Ibid.*, p. 113.

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more time at the Institute than was required, he even went so far as to pay for materials out of his own pocket.

Vergara Lope's personal life was unsettled and perhaps sad. After devoting all his strength, efforts and money to physiological research, he died in poverty; forgotten and even attacked by younger physicians of the period, including some whom he had on occasion helped.¹⁰

High-Altitude Medicine Worldwide

Descriptions of the effects suffered by those who ascend to elevations over 2,500 metres above sea level are quite ancient,¹¹ but the scientific study of high-altitude medicine really began early in the eighteenth century, continuing into the late twentieth century. In earlier periods, symptoms were described and strange explanations of "mountain sickness" were proposed.¹²

Paul Bert (1833–86) was one of the most important pioneers in the scientific study of high altitudes. In 1878, he published *La pression barométrique. Recherches de physiologie expérimentale*.¹³ As was common at the time, Bert described the symptoms shown by people who climbed mountains, but his original contribution to the knowledge of high-altitude physiology consisted in demonstrating that the effects of low pressure could be explained on the basis of the reduction of the partial pressure of oxygen. High-altitude hypoxaemia was inevitable and caused damage, while low pressure—in and of itself—was innocuous; a situation that was not fully understood until much later. In his book, Bert describes the use of the low-pressure chamber, a research strategy that allowed him to reach important conclusions. He also demonstrated that, regardless of barometric pressure or the concentration of O₂, the lethal level of oxygen pressure (PO₂) was always exactly the same. Bert's experiments are considered classics in this field. Another physiologist, Angelo Mosso (1846–1910) from Turin, also made numerous observations using a low-pressure chamber, but he was unable to confirm Bert's results and in 1898 postulated that "high-elevation sickness" was caused by the lack of carbon dioxide (CO₂); a phenomenon to which he gave the name "*acapnia*".¹⁴

In 1913, two Englishmen, C Gordon Douglas (1882–1963) and John S Haldane (1860–1936), published their findings on the ascent of Pike's Peak (at 4,300 metres above sea level and 460 mm Hg). Their most important conclusion concerned the apparent pulmonary

¹⁰ A C Rodríguez de Romo, 'Un científico mexicano y su visión romántica de la fisiología de las alturas', *Ciencia y Desarrollo*, 2000, 24: 40–7.

¹¹ See, for example, Fray José de Acosta's 1590 description of "mountain sickness", in Paríaca, Perú. José de Acosta, *Historia natural y moral de las Indias*, introduction, appendix and anthology by Barbara G Beddal, Valencia, Valencia Cultural, 1977, pp. 140–6.

¹² For example, it was thought that barometric pressure was important for maintaining the head of the femur in its socket, and that high elevations caused the muscles around it to work in excess in order to keep this articulation in place. This extraordinary effort

was the cause of fatigue. J B West (ed.), *High altitude physiology*, Stroudsburg, PA, Hutchinson Ross, 1981, p. 14.

¹³ P Bert, *La pression barométrique. Recherches de physiologie expérimentale*, Paris, Masson, 1878. Bert dedicated his book to Denis Jourdanet and expressed his appreciation to Jourdanet for having provided him with the material for his research and the idea that he proposed as a result of his research in Mexico.

¹⁴ Angelo Mosso, *Life of man on the high Alps*, transl. E Lough Kiesow, London, T F Unwin, 1898, pp. 289–92.

secretion of O₂.¹⁵ In 1921, Joseph Barcroft (1872–1947) organized an expedition to the Cerro de Pasco in Peru, but found no evidence of the pulmonary secretion of O₂. According to Barcroft, the tendency of the arterial saturation of O₂ to decline during exercise at high altitudes could be explained by the rupturing of the equilibrium of PO₂ in the pulmonary capillaries; a factor that limited O₂ consumption at higher elevations.¹⁶

The increase in the concentration of haemoglobin was one of the earliest proposals related to compensating mechanisms at high altitudes. In 1882, Bert published a study on this idea,¹⁷ and in 1890, François Viault (1849–1918) published his own observations on the phenomenon known as high-altitude polycythemia, based on a trip he had made to Morococha, Peru, a year earlier.¹⁸ In 1913, Mabel FitzGerald (1872–1973) reported an increase in haemoglobin among residents of the mountains of Colorado in the United States.¹⁹ In this same study, FitzGerald called attention to the relationship that exists between alveolar PCO₂ and altitude.

The first contributions to the study of high-altitude physiology date from between 1890 and 1920. At that time, mountain-climbing was in fashion, and experimental medicine was in its heyday. Scientists from many countries became interested in the influence of the atmosphere on health,²⁰ Vergara Lope among them. Before 1920, those who contributed most to this field were the Frenchman Paul Bert, the Italian Angelo Mosso, and the English researchers John Haldane and Mabel FitzGerald.

The Work of the Mexican Physiologist

Vergara Lope described physiological and anatomical mechanisms that characterized the adaptation to high elevations. This was a novel contribution during the period, and he was the first physiologist to undertake a completely medical approach and to offer explanations (physiological, anatomical and anthropological) of the problems of respiration at high altitudes.

He proposed the existence of a phenomenon of acclimatization to high altitude based on certain physiological and anatomical modifications. Two very important changes for him were hyperventilation and polyglobulia. With respect to hyperventilation, it should be noted

¹⁵C G Douglas, J S Haldane, Y Henderson and E C Schneider, 'Physiological observations made in Pike's Peak, Colorado with special reference to adaptations to low barometric pressure', *Phil. Trans. Royal Soc., Series B*, 1913, **203**: 185–9, 195–200, 308–9.

¹⁶J Barcroft *et al.*, 'Observations upon the effect of high-altitude on the physiological process of the human body, carried out in the Peruvian Andes, chiefly at Cerro de Pasco', *Phil. Trans. Royal Soc., Series B*, 1923, **211**: 351–3, 355–62, 450–4, 479–80.

¹⁷P Bert, 'Sur la richesse en hémoglobine du sang des animaux vivant sur les hauts plateaux', *Comptes Rendus de l'Académie des Sciences*, 1882, **94**: 805–7.

¹⁸F G Viault, 'Sur l'augmentation considérable du nombre des globules rouges dans le sang chez les habitants des hauts plateaux de l'Amérique du Sud',

Comptes Rendus hebdomadaires des Séances de l'Académie des Sciences, 1890, **111**: 917–18.

¹⁹M P FitzGerald, 'The changes in the breathing and the blood at various high altitudes', *Phil. Trans. Royal Soc., Series B*, 1913, **203**: 351–8, 370–1.

²⁰One important indication of this interest was the fact that numerous studies on high-altitude physiology were submitted to the Smithsonian Institution. In the 1895 concourse in which Vergara Lope participated, the following studies were received: 66 from the USA, 40 from France, 33 from Germany, 19 from England, 8 from Italy, 6 from Russia, 9 from Austria-Hungry, 4 from Denmark, and one each from Belgium, Scotland, Ireland, Norway, Bohemia, Finland, Spain, Bavaria, Switzerland, Serbia, India, Canada, Mexico and Argentina. *Annual Report of the Board of Regents of the Smithsonian Institution*, Washington, Government Printing Office, 1895, p. 12.

that Bert did not believe this actually occurred. Rather, he argued that those who live at high elevations made no attempt to struggle against oxygen deficiency by increasing their respiratory frequency (in this sense, Bert's thinking was similar to that of Denis Jourdanet). If such a struggle did take place, it would be caused by the acceleration or greater extent of the respiratory act itself. According to Bert, such acceleration did not occur, and it would have been most difficult to prove greater depth of inspiration through measurements.²¹

Our study deals specifically with Vergara Lope's experimental results concerning hyper-ventilation. Vergara Lope published his earliest findings on the increase of respiratory frequency in 1890. The first known report on hyperventilation appears in a book by Mosso of 1898. This demonstrates that Vergara Lope was indeed a pioneer in postulating hyper-ventilation as a compensatory mechanism for high-altitude hypoxaemia.

Today we know that the increase in ventilation reduces the decrease in arterial PO₂ and, as a result, the supply of O₂ to tissues; a process that is recognized as one of the most important compensating mechanisms of high-altitude physiology. For this reason, Vergara Lope's proposals are still relevant, even though he cannot take full credit for discovering them.

Between 1890 and 1926, Vergara Lope published three books²² and some forty papers on a variety of topics, though all related to moderate or high-altitude physiology. In 1891, he described high-altitude polycythemia²³ (he was unaware then that Bert [1882] and Viault [1890] had already published the same observations), and by 1912 he had concluded that this phenomenon was not associated with the overproduction of red blood cells.²⁴ His work on hyperglobulia at high elevations is so abundant that it constitutes material for another analysis in itself.

As early as 1894, Vergara Lope began to use compressed, rarefied air in treating patients with respiratory and cardiac problems.²⁵ He carefully studied changes in arterial tension and the concentration of erythrocytes in relation to atmospheric pressure and variations in blood gases.²⁶ Due to limits of space, we cannot describe in detail all of Vergara Lope's contributions to bettering our understanding of high-altitude physiology, nor is it the aim of this study to recount and analyse in detail each and every one of his contributions. The best evidence of his labours can be found in his publications in the leading scientific journals in Mexico in the late nineteenth and early twentieth centuries. In summary, for many years

²¹ Cited by West, *op. cit.*, note 12 above, pp. 358–9.

²² D Vergara Lope, *Refutación teórica y experimental de la teoría de la anoxihemia barométrica del Dr. Jourdanet*, México, Oficina Tipográfica de la Secretaría de Fomento, 1890; *idem*, *La anoxihemia barométrica. Medios fisiológicos y mesológicos que ayudan al hombre a contrarrestar la acción de la atmósfera rarificada de las altitudes: la tuberculosis en las altitudes, estudio practicado en el Instituto Médico Nacional*, México, Oficina Tipográfica de la Secretaría de Fomento, 1893; A L Herrera and D Vergara Lope, *La vie sur les hauts plateaux. Influence de la pression barométrique sur la constitution et le développement des êtres organisés*, México, Imprimerie Escalante, 1899.

²³ D Vergara Lope, 'La anemia de las alturas o la anoxihemia', *El Estudio*, 1891, 2: 65–8.

²⁴ D Vergara Lope, 'La hiperglobulia de las altitudes no es fenómeno de hematopoesis', *Gaceta Médica de México*, 1912, 7: 417–24.

²⁵ D Vergara Lope, 'Estudios acerca de las aplicaciones terapéuticas del aire enrarecido', *Memorias de la Sociedad Científica Antonio Alzate*, 1894, 8: 111.

²⁶ D Vergara Lope, 'Los aparatos para el estudio químico de la respiración del hombre y de los animales', *Anales del Instituto Médico Nacional*, 1900, 4: 367–73; *idem*, 'Las variaciones de la tensión sanguínea en relación con las de la presión barométrica', *Gaceta Médica de México*, 1906–7, 1: 64–77; *idem*, 'La densidad de la sangre y la tensión en los habitantes de las altiplanicies de gran altitud', *Gaceta Médica de México*, 1912, 8: 317–30.

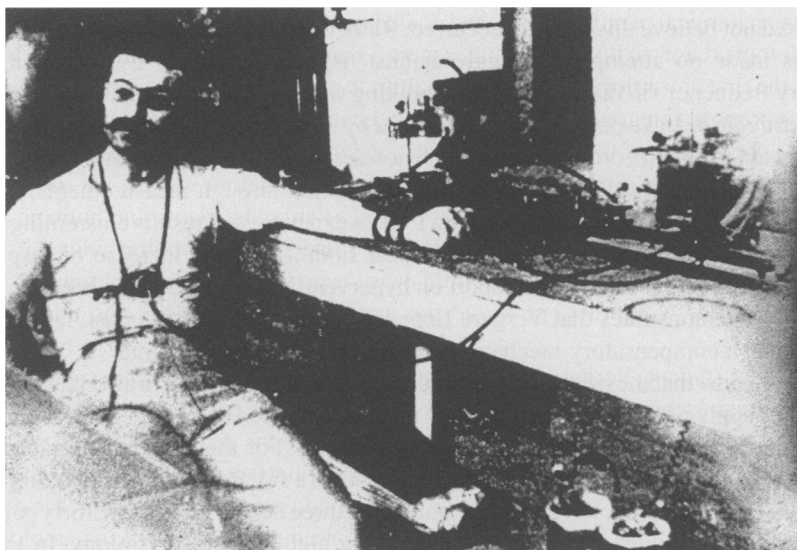


Figure 1: Daniel Vergara Lope Escobar, between twenty-five and thirty years old. From F Fernández del Castillo, *Historia bibliográfica del Instituto Médico Nacional*, México, Imprenta Universitaria, UNAM, 1961.

Vergara spent his time measuring the size of his compatriots' thoraxes, as well as their height, weight, respiratory and cardiac capacity, the volume of the air and oxygen they breathed, and their pulse, respiratory frequency, arterial pressure, red blood cell count and the chemical phenomena of gases. In the final phase of his career, Vergara Lope devoted himself to anthropometry,²⁷ with the objective of defining the anatomical parameters of Mexican bodies in relation to the geographical conditions of their environment. In his research, Vergara Lope used a wide variety of devices to measure Mexican bodies, many of which—including the cyrtometer, the thoracograph and the ortho-radiograph—were his own inventions.²⁸

The results of his experimental work led Vergara Lope to propose the “law of compensation”, according to which the medical problems generated by the rarefied air and lower pressure at higher altitudes were balanced (compensated) by proportional increases in the number of respirations, pulsations and red blood cells (high-altitude polycythemia). This law speaks of a kind of environmental adaptation. In addition, these physiological changes

²⁷ A C Rodríguez de Romo, ‘La mesure et la valeur. Un document d’anthropométrie mexicaine’, in Patrice Bret (ed.), *Le mémoire de la science*, Paris, Académie des Sciences, in press.

²⁸ D Vergara Lope, ‘Toracógrafo del Dr. Vergara Lope presentado ante la Academia Nacional de

Medicina en la sesión del 30 de junio de 1909’, *Gaceta Médica de México*, 1909, 4: 760–4; ‘Una nueva e importante aplicación de la orto-radiografía por el Dr. D. Vergara Lope’, *Gaceta Médica de México*, 1910, 5: 174–85; ‘Nuevo cirtométrógrafo del Dr. Vergara Lope’, *Gaceta Médica de México*, 1911, 6: 135–6.

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brought on anatomical manifestations, and could be interpreted mathematically. This meant that physiological and anatomical changes were a matter of proportionality. Thus, Vergara Lope was the first physiologist to study high-altitude medicine in a comprehensive way, and the first to propose integrated compensating mechanisms.

In 1895, the winner of the silver Hodgkins medal for the study of high-altitude physiology, sponsored by the Smithsonian Institution in Washington, was *La vie sur les hauts plateaux*.²⁹ A book of some 800 pages that examines animals, plants and humans at high elevations, it was written in French by Vergara Lope in collaboration with Alfonso L Herrera (1860–1942), a naturalist. Herrera was responsible for the sections on plants and animals, while Vergara Lope wrote the parts on human physiology, anatomy and pathology.

As a medical student, Vergara Lope had read *Le Mexique et l'Amérique tropicale* by the French physician Denis Jourdanet (1815–1892), in which the author presented his impressions concerning the influence of altitude on the life of the inhabitants of the Anahuac Valley, in Central Mexico.³⁰ One of Jourdanet's most important conclusions was the theory of "barometric anoxaemia", which held that under conditions of lower barometric pressure and a lower concentration of oxygen, there existed a greater predisposition to pathology that impoverished intellectual capacity.³¹

According to Vergara Lope himself, he read Jourdanet's book in the early months of 1889, and in May of that same year he began his experiments at the Instituto Médico Nacional, in which he set himself the task of finding sound scientific reasons for refuting Jourdanet's theory.³² On 23 May 1890, he defended his results in order to obtain the degree of "medical surgeon".³³ Also in 1890, he published a study refuting the theory of anoxaemia, entitled, *Refutación teórica y experimental de la teoría de la anoxemia barométrica del Dr Jourdanet*. His conclusion was that the theory of barometric anoxaemia was false, and he provided experimental data supporting this affirmation, crystallized in what he called the "law of compensation".

²⁹ In October 1891, Thomas George Hodgkins had donated \$200,000 to this Institution, stipulating that it should be devoted to "research and investigation on atmospheric air, in connection with the welfare of man". G B Goode (ed.), *The Smithsonian Institution, 1846–1886: the history of its first half century*, Washington, 1897, p. 241. The first convocation for this award was published in March 1893 in the leading scientific journals of the world. The deadline for submitting research papers was 31 December 1894, and some 218 papers were received. The results were announced on 9 August 1895. The terms of this competition were very specific: three prizes were to be granted, the first of which was worth ten thousand dollars, for "some new and important discovery in regard to the nature of [the] properties of atmospheric air". It was awarded to Lord Raleigh and William Ramsey from London, for the discovery of argon. The second prize, of two thousand dollars, was for the study of the properties of atmospheric air and its relation to

the natural sciences. It was not awarded because "no contestant complied strictly with the terms of the offer". The third prize—for the "best popular treatise upon atmospheric air"—was granted to Henry de Varigny, a Parisian. The committee considered, however, that there were some outstanding works to which it had been unable to give a prize, despite their high merit, and Vergara Lope's was the first study on this list; thus, he was awarded a silver medal. *Annual Report of the Board of Regents of the Smithsonian Institution to July 1895*, Washington, Government Printing Office, 1896, pp. 11–14.

³⁰ D Jourdanet, *Le Mexique et l'Amérique Tropicale: climats, hygiène et maladies*, Paris and London, J B Baillièrre et fils, 1864.

³¹ *Ibid.*, pp. 221–2.

³² Vergara Lope, *La anoxiemia barométrica*, op. cit., note 22 above, p. 4.

³³ Archivo Histórico de la Facultad de Medicina, UNAM, *Expedientes de alumnos*, leg. 58, exp. 5.

The Data from 1893

We chose the results on respiratory frequency published in Vergara's 1893 book, *La anoxihemia barométrica*, because it includes his earlier findings from 1890. His earliest experimental data appear in both publications, in support of the mechanism that he proposed was most important in the adaptation to high elevations; that is, the increase in respiratory frequency. These results are sufficiently abundant to allow us to follow his studies of respiratory frequency and also vital capacity; two of the principal parameters upon which he based the "law of compensation". Vergara used the term respiratory frequency in the same sense that it is used today; while he referred to "vital capacity" indiscriminately as "respiratory capacity", "size of the thorax" and, at times, "mean capacity" or "pulmonary air capacity"; assigning it an average value of between 3.5 and 4 litres.

Part of the sub-title of this study is: 'Tuberculosis at high altitude: a study undertaken at the National Institute of Medicine'. This book is well written in the sophisticated style that was fashionable at the time. The introduction is concise and attractive, and leads the reader to imagine that he or she is about to encounter something novel concerning an original topic. Vergara Lope asked how it was possible that Jourdanet's theory had survived for thirty years without anyone questioning it. In Vergara Lope's time, it had been suggested that the Valley of Mexico was, in fact, a kind of "magic mountain", containing all of the qualities necessary to treat people with anaemia, sclerosis, tuberculosis and neurasthenia.³⁴ His treatise is divided into five sections, throughout which it transmits an intense nationalist sentiment. The first section is devoted to a detailed description of Jourdanet's original theory. The second deals with the physiological responses and anthropometric changes that, according to Vergara, compensate for the deficient oxygen level at high altitudes. The third discusses the action of light and temperature on acclimatization to high altitudes, while the fourth refers to the phenomenon of acclimatization in general. In addition to refuting Jourdanet's theory, the final section defends the beneficial role of high altitudes in the treatment of tuberculosis.

Vergara Lope cites the principal authors of his time in this field. Though it may have been relatively simple for him to obtain his compatriots' publications, gaining access to foreign publications in a world that lacked modern means of communication could not have been quite so simple a matter. As the title of the book suggests, he carried out experiments and, even climbed the Popocatepetl volcano accompanied by groups of people with very diverse characteristics in order to take measurements of many physiological variables. His results are presented in three tables at the end of the text, which include data from 50 (including 10 women), 53 and 16 patients respectively (although 7 of the patients in the third chart were also included in the second). For each of these patients, Vergara Lope measured what he called the mean thoracic circumference, thoracic excursion, the length of the sternum from the notch to its point of union with the xiphoid appendix, respiratory capacity (vital capacity), the quantity of air inspired (tidal volume), the number of respirations, the number of pulsations, the level of haematocrit, and the number of red and white blood cells and the ratio between them. He also noted the name, age, height, weight, profession and state of

³⁴ Vergara Lope, *La anoxihemia barométrica*, op. cit., note 22 above, p. 5.

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health of each subject (see Table 1, for data on age, height and weight). In his view, the increase in pulmonary respiratory capacity was the key to acclimatization.³⁵ To prove this, he processed his results arithmetically.

How Vergara Lope carried out his Measurements

Before analysing the findings in Vergara Lope's *La anoxihemia barométrica*, it is worth mentioning that when evaluating his measurements he also took into account the humidity and temperature of both the environment and of the subjects he studied. In addition, he noted their ages, and went to great lengths to assure that they were as comfortable as possible. His methodology for measuring respiratory frequency will be examined in a separate section, as it is the central objective of this study.

Humidity

In 1919, Vergara Lope stated:

... I am the first [person] in Mexico to demonstrate ... the relationship between cause and effect that exists among the hyperglobulia, rarefaction and aridity that are characteristic of atmospheric air; to such a degree that there exists an almost mathematical proportionality between the intensity of the former [hyperglobulia] and the degree reached by such climatological factors. I was also the first to point out the modifications in the normal form and line of the sphygmograph among inhabitants of Mexico, which are observed as a result of the same causes already mentioned: blood density and the pressure at which it circulates through our blood vessels.³⁶

In order to carry forward his research, Vergara Lope measured the mean relative humidity in different parts of the country and affirmed, for example, that between altitudes of 1,000 metres and 2,000 metres the relative humidity ranged from 77 to 60 per cent; while between 2,000 and 2,600 metres, it varied from 67.5 to 48.4 per cent.³⁷

Age

For his studies, Vergara used people ranging from a five-month-old baby³⁸ to 77-year-old adults. In the extreme age ranges, he measured—principally—the blood cells and respiratory frequency. He also undertook a special anthropometric study of children in an orphanage, in which the measurement of respiratory frequency was important.³⁹ The results of these studies were not published, although in the Archivo General de la Nación (General Archives of the Nation) there is a highly detailed report that includes graphs, tables and photographs. In the book he wrote with Herrera, *La vie sur les hauts plateaux*, there is an abundance of tables that summarize his measurements, including those of men and women of diverse ages and also children.⁴⁰

³⁵ *Ibid.*, p. 28.

³⁶ D Vergara Lope, 'La hematología de las altitudes', *Gaceta Médica de México*, 1919, 54: 4.

³⁷ *Ibid.*, p. 9.

³⁸ *Ibid.*, p. 11.

³⁹ Archivo General de la Nación, *Informe del doctor Daniel Vergara Lope, de sus mediciones*

antropométricas en niños del hospicio, 1905, Secretaría de Instrucción Pública y Bellas Artes, galería 5, caja 132, exp. 3.

⁴⁰ Herrera and Vergara Lope, *op. cit.*, note 22 above, pp. 472, 473–5, 479. Figures for 77-year-old adults appear in D Vergara Lope, 'Hematología de las altitudes en sus relaciones con la clínica y la

Temperature

Vergara Lope knew that the atmospheric temperature decreases proportionally with the degree of rarefaction of the atmosphere. According to his measurements, however, the temperature of men (and animals) remained “*exactly the same*” (emphasis in the original) as that of the men and animals of the temperate climates of Europe.⁴¹ In *La vie sur les hauts plateaux*, Vergara Lope devoted many pages to his reflections and experiments on the temperature of the environment of animals and men.⁴²

The Relationship between Respiratory Frequency and Atmospheric Pressure

According to Vergara Lope, the average number of respirations per minute of permanent inhabitants of the high plateau was 22, a figure that characterized a third (31 subjects) of the people in a group of 103 individuals, whose values ranged from 17 to 30.⁴³ In Mexico, the barometric pressure is 580 mm Hg, while in Paris the average respiratory frequency was 17, at a barometric pressure of 750 mm Hg.⁴⁴ Upon dividing these two pairs of values, Vergara Lope obtained the following:

$$750/580 = 1.293 \text{ and } 22/17 = 1.294.$$

A difference of only one one-thousandth in the coefficient was so insignificant that the following ratio could be established:

$$750:580 \text{ as } 22:17 \text{ (750 is to 580 as 22 is to 17).}$$

According to Vergara Lope, then, the law of compensation would state the following: “respiratory frequency is directly proportional to altitude and inversely proportional to atmospheric pressure”. In other words, the number of breaths taken per minute increases at higher altitudes and lower pressures.⁴⁵

The Relationship between Vital Capacity and Atmospheric Pressure

Vergara stated that, according to the books of his time, the mean respiratory capacity in Paris was 3 litres, while according to his measurements the mean for altitude dwellers in

terapéutica’, *Memorias de la Sociedad Científica Antonio Alzate*, 1895, 1: 148–9.

⁴¹D Vergara Lope, ‘La atmósfera de las altitudes y el bienestar del hombre’, *Memorias de la Sociedad Científica Antonio Alzate*, 1895–96, 9: 182; *idem*, ‘La calorificación dans les altitudes’, *Memorias de la Sociedad Científica Antonio Alzate*, 1896–97, 10: 49–59.

⁴²Herrera and Vergara Lope, *op. cit.*, note 22 above, pp. 534–44.

⁴³Although here we consider only the values obtained up to 1893, it is important to mention that Vergara Lope continued to measure respiratory frequency, and that his results were always similar. Herrera and Vergara Lope, *op. cit.*, note 22 above, pp. 464, 472–5.

⁴⁴Vergara Lope took these data from the work of

P Bert, *La pression barométrique*, (*op. cit.*, note 13 above), who, in turn, reported that he had taken the same data from D Jourdanet, *Influence de la pression de l’air sur la vie de l’homme*, Paris, Masson, 1875, vol. 2, p. 330. According to Jourdanet, the figures for Mexico City are as follows: barometric pressure, 57 cm Hg, elevation, 2290 metres above sea level (he does not mention respiratory frequency). The figures for the city of Paris are: barometric pressure, 75 cm Hg, elevation, 212 metres above sea level, and respiratory frequency, 17 per minute. Vergara Lope accepted the figures for Paris, but took his own measurements for Mexico City; thus he used a barometric pressure of 580, instead of Jourdanet’s 570.

⁴⁵Vergara Lope, *La anoxiemia barométrica*, *op. cit.*, note 22 above, p. 40.

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Mexico was to be placed at around 4 litres. Upon applying the above “rule of proportionality”, we find:

4 litres/3 litres = 1.33 litres, and 750 mm Hg/580 mm Hg = 1.29.

This slight difference of just four-hundredths is so small that it can be discarded, leaving the following ratio:

4 litres:3 litres as 750 mm:580 mm.

This result allowed Vergara Lope to confirm the law that had emerged previously from his analysis of respiratory frequency: “vital capacity is directly proportional to altitude and inversely proportional to atmospheric pressure”. To put it another way, the lower the pressure and the higher the altitude, the greater the respiratory capacity.⁴⁶ At this stage, he observed something of tremendous importance: the difficulty of measuring respiratory capacity. He wrote that it was not easy to establish respiratory capacity with great accuracy, because in order to obtain valid readings it was necessary to have one’s own well-constructed apparatus, know how to handle it well, and train the subject who was to be observed. Taking these difficulties into account, Vergara Lope acknowledged that it was preferable to obtain the thoracic circumference and excursion, as they were more easily measured.

Vergara Lope was aware of the importance of correct measurements, and stated:

The measurement of the mobility of the thoracic cage is tremendously important. The capacity for inspiration does not depend so much on the greater or lesser circumference of the thorax, as on the degree of mobility that the cage can attain; the circumference, in effect, may vary according to the quantity of adipose and connective tissue, as well as to muscular development. The dilatation of the thorax varies according to the place in which it is measured. We found maximum excursion at the level of the epigastrium and then at the level of the xiphoid appendix. It is at this level that we carry out our measurements in Mexico.⁴⁷

Vergara Lope devoted great effort to his measurements of thoraxes, and measured an enormous number of subjects.⁴⁸ In addition to using the manual method, he also employed instruments.⁴⁹

He concluded that when the blood “is thirsty for oxygen at the altitude of the Valley of Mexico”, the first step that the compensatory mechanism takes is to increase the respiratory frequency to a mean figure of 22 per minute. This is the indispensable prelude that triggers the other responses, including the acceleration of the pulse and—if fatigue is present—an increase in vital capacity that enriches the blood flow.⁵⁰

We will next examine Vergara Lope’s results in the light of our present-day knowledge.

Method

We used physiological information of the 112 subjects that Vergara Lope studied and later presented in the three tables of his 1893 book, to set up a database. Duplicated

⁴⁶ Ibid. p. 48.

⁴⁷ Herrera and Vergara Lope, op. cit., note 22 above, p. 482.

⁴⁸ Vergara Lope, *La anoxihemia barométrica*, op. cit., note 22 above, pp. 38, 41; Herrera

and Vergara Lope, op. cit., note 22 above, pp. 374–400, 446.

⁴⁹ Vergara Lope, see articles cited in note 28 above.

⁵⁰ Vergara Lope, *La anoxihemia barométrica*, op. cit., note 22 above, p. 41.

Table 1
Description of the population studied by Vergara Lope

Variable	N	Mean	SD
Age	111	33.3	14.7
Altitude (m)	95	2237.0	411.0
Height (cm)	111	164.2	7.0
Weight (kg)	45	62.7	7.8
Thoracic circumference (cm)	53	89.9	6.3
Vital capacity (L)	110	4.8	1.3
Breathing frequency (min ⁻¹)	111	22.8	2.4
Heart rate (min ⁻¹)	111	79.2	10.2
Haemoglobin (g/dL)	51	14.7	1.2
Erythrocyte count (millions/mm ³)	51	6.3	1.3
Body mass index (Kg/m ²)	45	23.2	3.2
Tidal volume (L)	53	0.57	0.10
Minute ventilation (L/min)	53	13.2	2.74
<i>Vital capacity as % of prediction for other populations</i>			
White North Americans*	110	109.3	40.0
Mexican-Americans*	110	109.0	39.5
Mexican workers (Pérez-Padilla and colleagues)	110	104.2	36.5
Europeans (Quanjer)	110	116.0	42.3
North Americans (Knudson)	110	121.3	50.5
Mexicans (Rodríguez Reynaga)	110	112.9	41.6

Data from the author's climb up the Popocatepetl volcano are included.

SD = standard deviation.

Subjects reported in Tables 1 and 2; n = 111; this figure includes ten women.

*White North Americans and Mexican-Americans from the third NHANES study (Hankinson and colleagues).

Sources: J R Pérez-Padilla, J Regalado and J C Vásquez, 'Reproducibilidad espirométrica y adecuación a valores de referencia internacionales en trabajadores mexicanos demandando incapacidad', *Salud Pública de México*, 2001, **43**: 113–21; Report of Working Party, 'Standardized lung function testing', *Bull. Eur. Physiopathol. Respir.*, 1983, **19**: Supp. 5, pp. 1–95; R J Knudson, M D Levowitz, D J Holberg and B Burrows, 'Changes in the normal maximal expiratory flow-volume curve with growth and aging', *Am. Rev. Respir. Dis.*, 1983, **127**: 725–34.

measurements of people who were studied on more than one occasion during ascents of the Popocatepetl volcano were eliminated, and the variables of age, sex, height, weight, respiratory frequency, tidal volume and vital capacity were taken into account. Expected vital capacity was calculated on the basis of data for height, age and sex for the adult Mexican population and for Mexican workers according to data obtained by J R Pérez-Padilla and

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colleagues (see Table 1 and Figure 5).⁵¹ These values were then compared with figures for Europeans, North Americans and Mexican-Americans.⁵²

The values for respiratory frequency, tidal volume and minute ventilation were similarly compared with others reported for Mexico,⁵³ and with figures for Tibetan and Aymaran populations living at approximately 4,000 metres above sea level.⁵⁴ Also included were figures for Peruvians living at sea level and in Morococha, at 4,450 metres above sea level (see Table 2 and Figure 2).⁵⁵

Vergara Lope obtained the people he studied through what would now be called a convenience sample, in which subjects are chosen on the basis of simple availability; although individuals who were clearly ill were eliminated. Nonetheless, Table 2 of his study shows that some of his subjects were convalescing from a variety of maladies. In the modern world, it would be indispensable to mention the exposure to tobacco—perhaps not overly common at that time—and to smoke from firewood (probably quite generalized), as well as to dust and chemical substances. Although the deleterious effects of smoke from tobacco or firewood were unknown at the time, the same cannot be said for the effects of dust upon workers, since it had been recognized from the Renaissance that miners suffered from dust-inflicted ailments. Vergara Lope may well have been aware of this, because in 1896 he published the results of a study that he had carried out among miners.⁵⁶ Nevertheless, the representativeness of the subjects whose responses to high elevations were studied can be questioned, though he stated that he did not choose only the most vigorous and included several convalescents. A sample of target populations would not have been very feasible, as it would have meant departing from the habitual methods of physiologists, who usually studied their colleagues and students. It is interesting to note that some of the subjects of this study would later become—or already were—prominent in Mexico; for example, Alfonso L Herrera, José Villada and Francisco Río de la Loza, who were referred to as “cultured persons from our society”. “Common people” (“*personas del pueblo*”), however, were also included. It is true that the most important adaptive and physiological changes of a species can be discerned clearly by studying only a few subjects. On the other hand, subtle and less constant changes require the study of much larger populations. It is fair to say that

⁵¹ J R Pérez-Padilla, J Regalado-Pineda and J C Vázquez-García, ‘Reproducibilidad espirométrica y adecuación a valores de referencia internacionales en trabajadores mexicanos demandando incapacidad’, *Salud Pública de México*, 2001, 43: 113–21.

⁵² P H Quanjer, Report of Working Party, ‘Standardized lung function testing’, *Bull. Eur. Physiopathol. Respir.*, 1983, 19: Supp. 5, pp. 1–95; R J Knudson, M D Lebowitz, C J Holberg and B Burrows, ‘Changes in the normal maximal expiratory flow-volume curve with growth and aging’, *Am. Rev. Respir. Dis.*, 1983, 127: 725–34; J L Hankinson, J R Odencrantz and K B Fedan, ‘Spirometric reference values from a sample of the general U.S. population’, *Am. J. Respir. Crit. Care Med.*, 1999, 159: 179–87.

⁵³ E Staines, J García-Trigueros and B Muñoz-Bojalil, ‘Algunos aspectos de la función

cardiopulmonar en la ciudad de México’, *Neumol. Cir. Tórax.*, 1971, 32: 369–86; B R Muñoz-Bojalil, ‘Estudios de ventilación pulmonar, de gases y pH en sangre arterial en sujetos sanos en la ciudad de México’, *Neumol. Cir. Tórax. Mex.*, 1972, 33: 133–8.

⁵⁴ C M Beall, K P Strohl, J Blangero, S Williams-Blangero, L A Almasy, M J Decker, C M Worthman, M C Goldstein, E Vargas, M Villena, R Soria, A M Alarcon and C González, ‘Ventilation and hypoxic ventilatory response of Tibetan and Aymara high altitude natives’, *Am. J. Phys. Anthropol.*, 1997, 104: 427–47.

⁵⁵ A Hurtado, ‘Animals at high altitude: resident man’, ch. 54, *Handbook of physiology: adaptation to environment*, American Physiological Society, 1964.

⁵⁶ D Vergara Lope, ‘Un caso de anemia de los mineros y tuberculosis incipiente’, *Memorias de la Sociedad Científica Antonio Alzate*, 1896–97, 10 (5–6): 169–82.

Table 2
Minute ventilation, breathing frequency, PCO₂ and pulse

Variable	Vergara-Lope	Mexico (Staines)	Mexico (Muñoz-Bojalil)	Lima (Hurtado)	Morococha (Hurtado)	Sherpas (3800-4000 m)	Aymaras (3800-4000 m)
N	53	300	35				
Minute ventilation (L/min)	13.2 (2.7)		8.7 (1.17)*	8.24 (0.17)	9.73 (0.30)	19.7 (8.4)	13.4 (2.4)
f (per min)	22.8 (2.4)	17 (2)	16 (3)	14.7 (0.5)	17.3 (0.46)	14.8 (3.4)	15.5 (2.8)
TV (L)	0.57 (0.10)		0.53*	0.6 (0.02)	0.59 (0.03)	1.4 (0.6)	0.9 (0.2)
PCO _{2et} (mmHg)			30.7†	38.6	29.1	29.7 (4.6)	33.8 (4.1)
Pulse (per min)	79.2 (10.2)					73 (13)	67 (11)

All data are for adult men. The subjects studied by Vergara Lope, Staines and Muñoz-Bojalil were examined at an altitude of approximately 2,240 metres. The data from Lima, Peru, were taken at sea level.

f = breathing frequency.

TV = tidal volume.

PCO_{2et} = partial pressure of CO₂ in a sample of air at the end of the respiration. In healthy subjects this is a good indicator of alveolar gas and of value in arterial blood.

*Calculated on the basis of predicted equations reported per square metre of surface area.

† = value in arterial blood.

Sources: E Staines, J García-Trigueros and B Muñoz-Bojalil, 'Algunos aspectos de la función cardiopulmonar en la ciudad de México', *Neumol. Cir. Tórax.*, 1971, **32**: 369-86; B R Muñoz-Bojalil, 'Estudios de ventilación pulmonar, de gases y pH en sangre arterial en sujetos sanos en la ciudad de México', *Neumol. Cir. Tórax. Mex.*, 1972, **33**: 133-8; A Hurtado, 'Animals at high altitude: resident man', ch. 54, *Handbook of physiology: adaptation to environment*, American Physiological Society, 1964.

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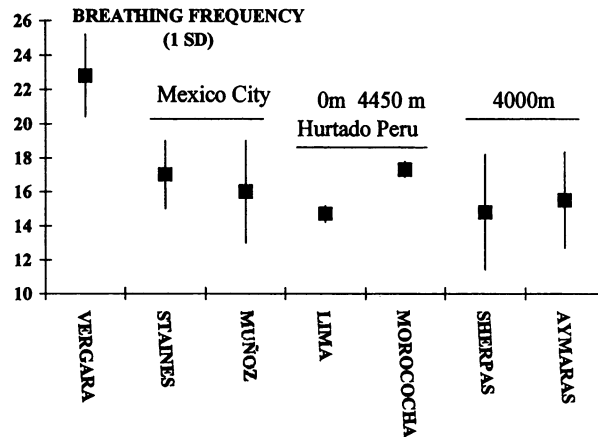


Figure 2: Breathing frequency per minute—the bar indicates the standard deviation—reported by Vergara Lope (and other authors) for healthy subjects at different altitudes. Observe that the breathing frequencies reported by Vergara Lope in Mexico City are greater than those given by other authors, including those reported for native Sherpas or Aymaras at much higher altitudes.

on the basis of the group he studied, Vergara Lope could detect the larger changes that, generally speaking, are most important from the point of view of adaptation.

The Measurement of Respiratory Frequency

Vergara Lope measured respiratory frequency manually, using a spirometer and Marey's pneumograph that could measure either directly or by transmission. The earliest such measurements he took in 1889 at the Beístegui hospital and the Instituto Médico Nacional, using colleagues from the School of Medicine. Later, he also used the Schnepf and Galante spirometer, in addition to Marey's sphygmograph.

Not wishing to leave the exactitude of the results only to the senses, and in order to gather the number of respirations and pulsations per minute with greater precision, I have seen fit to employ three apparatuses: the pneumograph modified by Marey, the transmission sphygmograph, also by Marey, and both apparatuses connected by a rubber tube with two inscription levers; which leave their marks in parallel and simultaneous fashion on a horizontal inscriber cylinder placed so as to give exactly one revolution per minute. [All the instruments] were calibrated to ensure perfect functioning, including a Schnepf spirometer, whose graduation was carefully rectified. [I thus] proceeded with my research.⁵⁷

In *La vie sur les hauts plateaux*, he commented:

Above all, the spirometer provides us with the volume of air that circulates through the lungs, during both inspiration and expiration. The pneumograph informs us as to the special mode of the mechanical act, of the particularities of the movement of the thorax in each one of the moments of respiration, as well as the degree of displacement of the different points of the thorax to which the

⁵⁷Vergara Lope, *Refutación teórica*, op. cit., note 22 above, pp. 32–5.

apparatus is applied. By placing three perfectly equal pneumographs in distinct locations, I have succeeded in demonstrating the differences that exist in the movements of the thorax among men, women and children.⁵⁸

On the basis of the observation of his graphs, Vergara Lope concluded that the inspiration curve was rectangular, and almost rectilinear. After that came the expiration curve that is regular at first, but then becomes irregular (see Figure 3). It is undulated and prolongs itself smoothly until the inspiration curve begins once again. He also noted that the highly angular curves corresponded to the contact of the heart with the thoracic wall (in the case of the gymnast, for example). Regarding all the lines, Vergara Lope pointed out that the graph part is reversed, in order—he said—to better distinguish the correspondence of the undulations with the points of the line from the sphygmograph.

In order to emphasize further his theory of the increase of respiratory frequency, Vergara Lope affirmed that as a consequence of this increment the size of the thorax also increases; this he illustrated by means of silhouettes that he drew himself.

[In indigenous people] the sternum is elevated to a great height, the prominence of inspiration extends to the entire abdomen . . . at the same time as the action of the respiratory muscles, the diaphragm, exercises a much greater pressure on the more mobile thorax, [thus] raising the sternum even higher than in Europeans.⁵⁹ [See Figure 4.]

Vergara Lope tried to make his subjects feel comfortable. For example, in order to suppress the inhibiting action of the brain—in so far as this was possible—they attentively read books throughout the experiments, so that their respiratory movements were perfectly automatic and independent of their volition.⁶⁰

Vergara described in some detail the use of the sphygmograph and Marey's pneumograph for measuring pulse and blood pressure. At the same time, he measured respiratory frequency. These apparatuses could be used directly or through transmission. He believed that the direct mode was more precise, because in the second case:

. . . the elastic column of air that transmits the movement to the inscribing-lever drum, cushions to some extent the impulse that the drum of the sphygmograph receives, [thus] losing, naturally, amplitude and perfection in the details of the line. It is necessary to give the elastic membranes of both drums a very weak tension, and reduce as far as possible the [pressure] of the lever on the cylinder of the polygraph.⁶¹

More specifically, he stated:

[I] place Marey's transmission sphygmograph on the radial flute of the wrist, in combination with the inscribing drum, thus obtaining a line on Foucault's cylinder with a regulator, placed in such a way that it gives one revolution per minute. In this way, the graph obtained was continuous during the entire duration of the experiences . . .⁶²

However, as previously noted, he commented on the difficulty of working with the spirometer. The use of this instrument (invented by John Hutchinson [1811–1861]) spread

⁵⁸ Herrera and Vergara Lope, op. cit., note 22 above, p. 480.

⁵⁹ Ibid., p. 481.

⁶⁰ D Vergara Lope, 'Acción del aire enrarecido sobre el hombre, *Memorias de la Sociedad Científica Antonio Alzate*, 1896, 1: 179.

⁶¹ D Vergara Lope, 'Hematología de las altitudes y su relación con la clínica y la terapéutica', *Revista Quincenal de Anatomía Patológica y Clínicas Médica y Quirúrgica*, 1896, 1 (7): 204.

⁶² Vergara Lope, *La anoxihemia barométrica*, op. cit., note 22 above, p. 14.

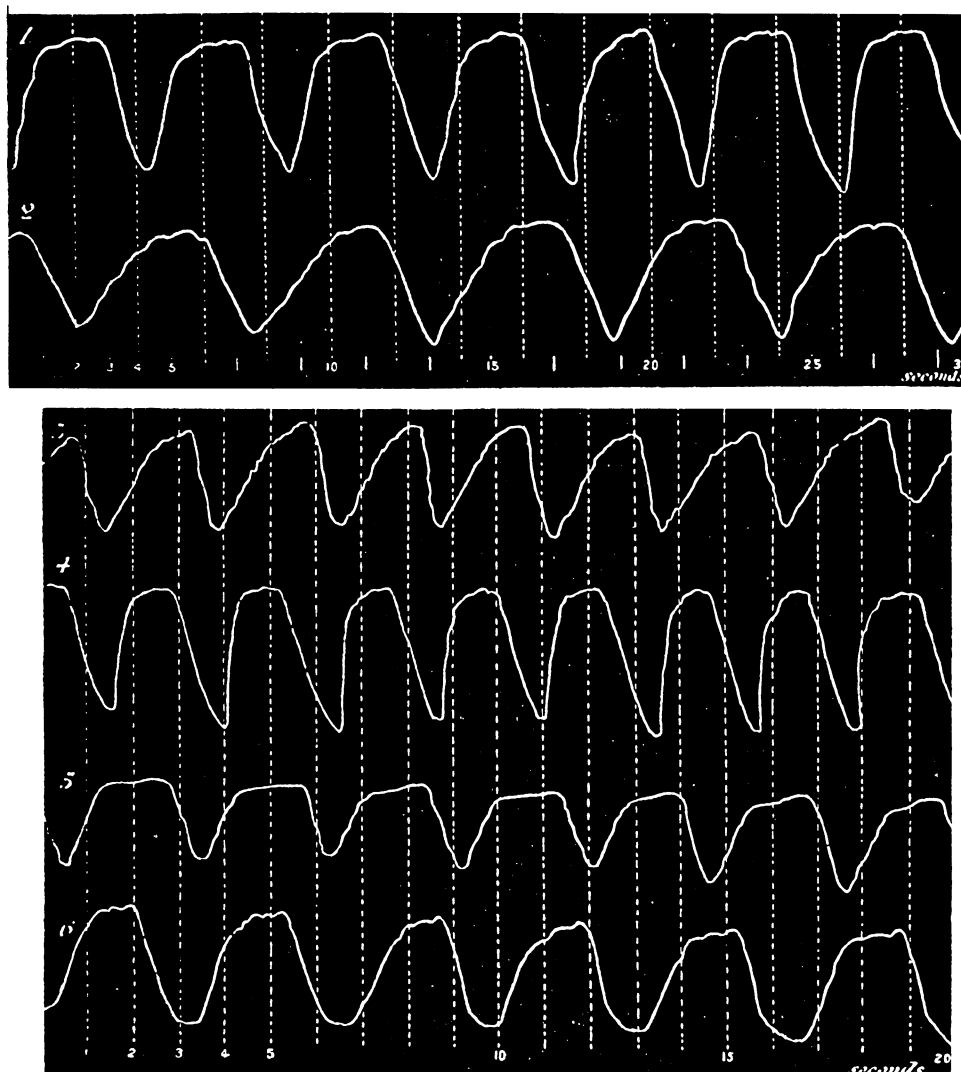


Figure 3: Vergara's graphs measuring the breathing of Mexicans. From A L Herrera and D Vergara Lope, *La vie sur les hauts plateaux. Influence de la pression barométrique sur la constitution et le développement des etres organisés*, México, Imprimerie Escalante, 1899, figure 90.

after 1864, and, presumably, despite the methodological problems that researchers of that period may have encountered, it was recognized as valid and reliable. We now know that a number of quality control measures are required, beginning with the instrument itself (Vergara said the first step was to have an instrument of one's own) but including procedures

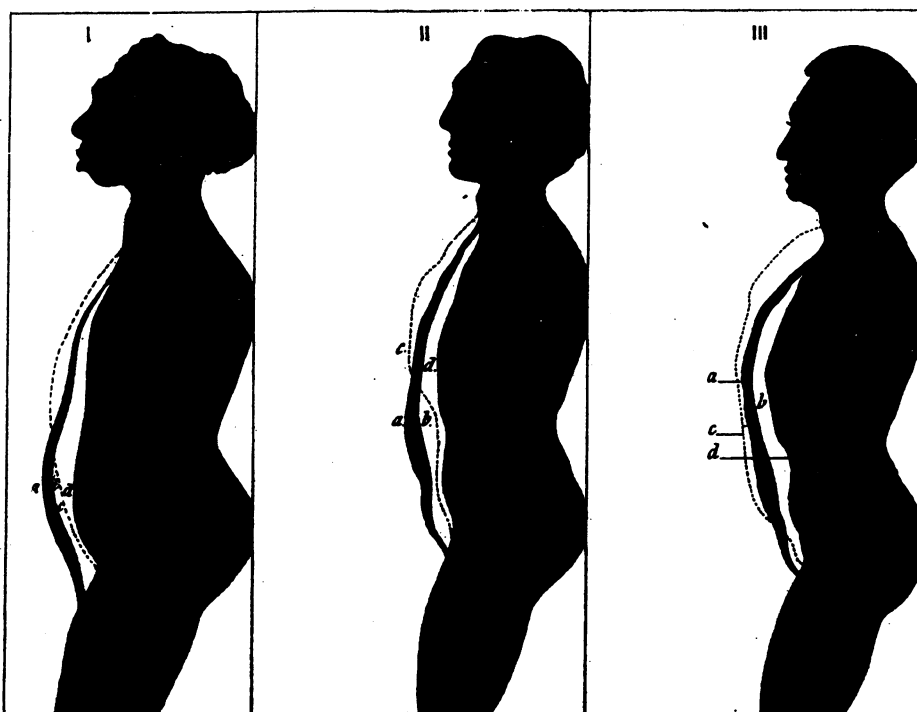


Figure 4: Silhouettes drawn by Vergara Lope showing the differences in the thoraxes of (from left to right) an African, a European, and an American Indian. From A L Herrera and D Vergara Lope, *La vie sur les hauts plateaux. Influence de la pression barométrique sur la constitution et le développement des etres organisés*, México, Imprimerie Escalante, 1899, figure 93.

to standardize the tests, the use of reference values and the interpretation of results.⁶³ By modern standards, Vergara's spirometric study could well be considered questionable. The spirometers then available were of the volumetric, water-sealed, bell type, that are able to measure volumes such as vital capacity. Today, both flow and, especially, forced respiratory volume in the first second (FEV_1) are among the measurements taken. They require low-inertia equipment and a precise response to high-frequency events; features that are not characteristic of early instruments of the metal bell type.

Spirometers need daily calibration with a syringe to assure reliability, though this can also be accomplished with a water displacement system that was available at the time. Bell spirometers are precise in the measurement of volume as long as there are no leaks, either in the bell itself or in the tubing that is put into the subject's mouth. Although he was trained in physiological methods, we do not know if Vergara Lope actually mastered such technical

⁶³ American Thoracic Society, 'Standardization of spirometry (1994 update)', *Am. J. Respir. Crit. Care Med.*, 1995, **152**: 1107–36; American Thoracic

Society, 'Lung function testing: selection of reference values and interpretative strategies', *Am. Rev. Respir. Dis.*, 1991, **144**: 1202–18.

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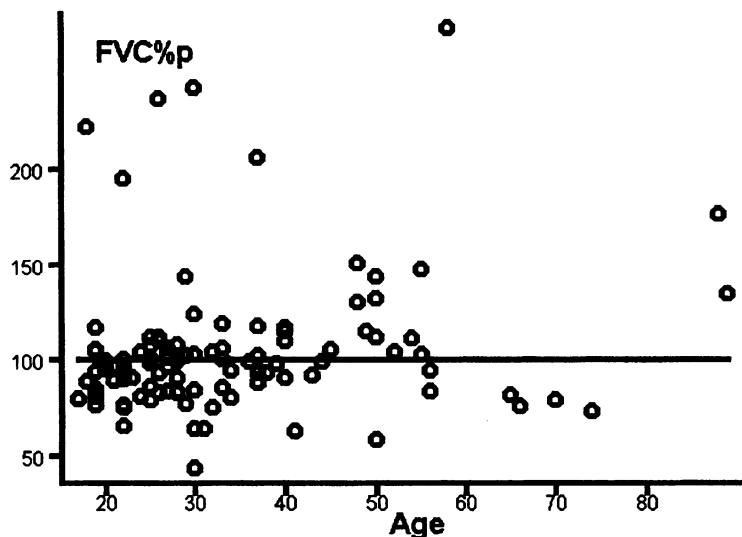


Figure 5: FVC%P is the vital capacity of subjects studied by Vergara Lope, expressed as a percentage of the values predicted for Mexican workers as a function of age. Though the means are clustered around 100, observe the dispersion of values, some of which are much higher than the mean. This may be the result of inaccuracies in the measurements. From D Vergara Lope, *La anoxihemia barométrica*, México, Oficina Tipográfica de la Secretaria de Fomento, 1893, unpaginated tables.

details. By the same token, the spirometric graph helps considerably in the interpretation of data and the evaluation of data quality. In his 1890 book, Vergara wrote: “In order to show the result obtained through this procedure, I also attach one of the tracings inscribed using this apparatus”.⁶⁴

A Modern Analysis of Vergara Lope’s Results

Table 1 contains a summary of the data that Vergara Lope reported in his first three charts. The group studied consisted almost entirely of men. The vital capacity indicated is not statistically different from the expected value for the modern Mexican population of the same size and age. Figure 5 shows the distribution of the values as a percentage of that which was predicted for a population of workers at the altitude of Mexico City. The data are widely dispersed and the results of some subjects fall far above or below those values, but there is no significant departure from the 100 per cent expected.

Table 2 presents the ventilatory pattern of the subjects studied by Vergara Lope, together with those of other Mexicans and of other subjects that live in elevated areas. It is clear that the respiratory frequency indicated by Vergara Lope (22 per minute) is considerably higher than the values reported for Mexicans a century later. In fact, it is also higher than the figure

⁶⁴Vergara Lope, *Refutación teórica*, op. cit., note 22 above, p. 35.

for the inhabitants of Tibet and the indigenous Aymara of Peru, who live at even higher altitudes (4,000 metres, Figure 2). In fact, the figure reported by Vergara Lope is similar to that found among people now living in Mexico City who suffer from respiratory ailments with interstitial lung diseases and chronic obstructive pulmonary disease.⁶⁵ In addition, the lowest frequency recorded was 17, and 83 subjects (75 per cent) had a frequency of between 20 and 24; all of which reveals a remarkable uniformity.

The wide dispersion of the values for vital capacity reported by Vergara Lope may well reflect, more than anything else, a certain degree of technical imprecision in his measurements. The standard deviation of these measurements, expressed as a percentage of the predicted values, is between 30 and 50 per cent; implying a coefficient of variation of at least 30 per cent; which is well above the 12 per cent that is normally observed among populations. This prompts the suspicion that both Vergara Lope's use of the spirometer and his method of taking measurements were imprecise. The averages obtained for men, however, are approximately 4 per cent higher than the reference figures found in recent studies of Mexican workers and—from the perspective of physiology—do not represent a significant difference. As these are figures that have been adjusted for height, age and sex, one possibility is that Vergara's subjects may have had a different ratio between length of trunk and stature; that is, the people were of the same height but had shorter legs and a larger thorax. In fact, the average height seems to be less than that currently found among the metropolitan population.

The breathing frequency documented by Vergara in the late nineteenth century is higher than that found in a recent study of the Mexican population. Indeed, it is faster than among inhabitants of higher elevations than those of Mexico, such as the Sherpas of Tibet and the Aymara of the Andean area; but it is similar to the frequency reported for people examined in Mexico City who suffered from restrictive pulmonary problems or emphysema, as mentioned above.⁶⁶ It is difficult to explain this difference solely on the basis of technical variations, because breathing frequency can be measured without equipment, using only observation and a chronometer. It is well-known that breathing through a mouthpiece can modify respiration patterns and that some time is required for a subject to become accustomed to such an apparatus. Even taking this into account, however, it is difficult to explain Vergara Lope's results in any satisfactory way by applying the parameters of modern technology. It is possible that the equipment was badly manufactured (perhaps with a great deal of "dead space") but this usually increases the depth of respiration in young adults, though frequency tends to rise in older ones.⁶⁷ Anxiety may increase frequency, although the usual response is an irregularity of depth.⁶⁸ Vergara Lope does mention,

⁶⁵ J C Vázquez, 'Respiración nocturna en pacientes con enfermedad pulmonar intersticial y enfermedad pulmonar obstructiva crónica en la ciudad de México, a 2240 m de altura sobre el nivel de mar', MA thesis in Medical Science, Universidad Autónoma de México, 1996; G Chi-Lem and J R Pérez-Padilla, 'Gas exchange at rest during simulated altitude in patients with chronic lung disease', *Arch. Med. Res.*, 1998, 29: 57–62.

⁶⁶ See Vázquez, and Chi-Lem and Pérez-Padilla in previous note.

⁶⁷ J N Han, K Stegen, K Simkens, M Caubergs, R Schepers, O Van den Bergh, J Clement and

K P Van de Woestijne, 'Unsteadiness of breathing in patients with hyperventilation syndrome and anxiety disorders', *Eur. Respir. J.*, 1997, 10: 167–76.

⁶⁸ F H Wilhelm, W Trabert and W T Roth, 'Characteristics of sighing in panic disorder', *Biol. Psychiatry*, 2001, 49: 606–14; J L Abelson, J G Weg, R M Nesse and G Curtis, 'Persistent respiratory irregularity in patients with panic disorder', *Biol. Psychiatry*, 2001, 49: 588–95.

however, that all the subjects of his study were calm, and “isolated from any exciting or depressing action”.⁶⁹ It is interesting to see how he attempted to attribute this ventilatory increase exclusively to the increase in respiratory frequency, with no modification in profundity. Curiously, what has been observed at moderate elevations is precisely the contrary; that is, respiratory frequency tends to remain constant while tidal volume increases, thus providing greater volume at the same rhythm. Vergara Lope himself observed that the respiratory frequency of some of the people who climbed the volcano lessened instead of increasing, but he did not know to what to attribute this phenomenon.⁷⁰ The variation of breathing frequency in Vergara’s subjects is very small, as 75 per cent showed between 20 and 24 per minute. Thus, it is not only the mean frequency that is unusual, but also the reduced variability, and this for a variable that can be measured very simply, with no other equipment than a watch. It is important to note that Vergara’s measurements of pulse are highly congruent with the figures he proposed for respiratory frequency: in a study of 825 people carried out in 1895, he found an average of 80 to 85 pulsations per minute; that is, the relation between respiratory movement and pulse was found to be 1-to-4.⁷¹

Discussion

Is Adaptation Perfect?

The most important change in the acclimatization process is the ventilatory increase (as Vergara Lope pointed out). Much less relevant are the increases in haemoglobin and the metabolic compensation for the acute hyperventilation that hypoxaemia triggers. A displacement of the oxygen dissociation curve with haemoglobin towards the left as happens genetically in llamas (in the Andes) or because of extreme hyperventilation and alkalosis in humans on Mount Everest, may promote oxygen intake from the atmosphere at extremely high altitudes. This is not, however, a normal finding at lower altitudes. Tissue changes—in flow or aerobic metabolism—take some time to occur, but can be of greater relevance.

In this sense, acclimatization to high altitudes would be perfect if the level of mixed or tissular PO₂ at high elevations were maintained at an identical level to that observed at sea level, both during rest and exercise; and if physical capacity at high altitudes and at sea level were also identical. In reality, however, this does not occur at moderate altitudes. The diminished tolerance for aerobic exercise in Mexico City compared to that observed at sea level has been well-known since the 1968 Olympic Games. In this sense, then, perfect acclimatization to high altitudes does not exist.

Returning to Jourdanet and Vergara Lope, we find a paradoxical situation. The Frenchman was correct in proposing the existence of the syndrome he called “barometric anoxaemia”, but the Mexican was correct in arguing that this condition was hardly likely to occur at the elevation of the Valley of Mexico. If Jourdanet exaggerated the impact of an elevation of 2,240 metres above sea level, then Vergara Lope exaggerated the degree of perfection of his mechanisms of acclimatization.

⁶⁹ Vergara Lope, *Refutación teórica*, op. cit., note 22 above, p. 35.

⁷⁰ Vergara Lope, *La anoxihemia barométrica*, op. cit., note 22 above, p. 69.

⁷¹ Vergara Lope, op. cit., note 61 above.

It is also relevant to distinguish between a short stay at high altitudes and a prolonged one. Some humans can climb Mount Everest without oxygen and remain there for a few minutes; though they are, of course, almost on the verge of death. On the other hand, it is not possible to remain at altitudes greater than 5,000 metres for months or years without experiencing corporal deterioration. At such altitudes, therefore, there is no such thing as permanent acclimatization.

Just as remaining on Mount Everest without oxygen is possible for a only a very few people and even then for only a few minutes at a time, long residence at lower altitudes may generate over time an effect that Carlos Monge Medrano (1884–1970) described as the loss of high-altitude adaptation (chronic mountain illness). This means that subjects who are apparently acclimatized to high elevations would eventually fall ill and die if they do not descend (Monge's disease). Vergara Lope understood chronic mountain disease very well and knew that the changes brought about by living permanently at high altitudes were not the same as those caused by the temporary adaptation of people who ascend gradually and then come back down. He described these experiences in articles published between 1894 and 1910 in *Memorias de la Sociedad Científica Antonio Alzate* and *Anales del Instituto Médico Nacional*.

Monge's disease is more frequent and has an earlier onset at higher elevations and in subjects who are more susceptible. It is less common and appears later at lower altitudes and in subjects with a greater capacity for acclimatization. Given that hypoxaemia is what triggers these phenomena, any factor that aggravates this condition (such as pulmonary illness or obesity) will exacerbate the loss of adaptation.

As is the case with any other bodily function, the degree of adaptability to high altitudes varies among human beings in a way that does not depend solely on training or aerobic capacity. The degree of ventilatory response to hypoxaemia, for example, is directly proportional to the capacity to ascend and inversely proportional to the frequency of the adverse effects of high altitudes. This confirms the preponderant role of hyperventilation in adaptation, as Vergara Lope pointed out. We now know that the response to hypoxaemia has an important genetic component⁷² and that Vergara Lope recognized the variability among humans and a predisposition to ill health, a phenomenon that at the time was known as diathesis.

Daniel Vergara Lope and his Circumstances

As already mentioned, despite the methodological difficulties of the period, Vergara Lope's values for vital capacity are similar to those of a modern population residing in Mexico. Vergara was a dedicated scientist and an obsessive experimentalist. His rigour in the implementation of the scientific method, in ensuring similar conditions for all his experiments, and in his use of mathematical and statistical interpretation permeates his work. Though he mentioned the apparatuses he used, unfortunately he did not speak clearly of the technical problems he may have encountered, nor how he overcame them. Such information might well have allowed us to present a better explanation of the results he obtained.

⁷² K A Fagan and J B Weil, 'Potential genetic contributions to the control of the pulmonary

circulation and ventilation at high-altitude, *High Altitude Medicine and Biology*, 2001, 2: 165–71.

The Mexican Response to high Altitudes in the 1890s

In order to comprehend Vergara Lope and his science, it is important to understand both the historical moment in which he lived and his own personal convictions. His Mexico was characterized by a deep yearning for a national identity and a desire to prove that its citizens had not been doomed by the geographical environment in which they were destined to live. What better than medical science—and above all, physiology—to resolve what he himself expressed as:

... a matter exclusively of national interest and notable transcendence for future progress, not only scientific, but also hygienic-practical and social ... Mexicans shall not be a miserable race, a fatal victim of the cosmic environment in which they find themselves and incapable of any kind of progress. To put all things in their proper place, that is my wish and that of all those who seek truth.⁷³

For Vergara Lope, the theory of “barometric anoxaemia” was not only false but had not taken into account the real physiological and anthropometric parameters of the Mexican population:

It was only a short time ago, when we looked back on things and attempted to establish our own national medicine, our own natural sciences, that we perceived with amazement that we still have to start along a road that we believed had already been travelled to a large degree. We do not know just what we are like, our height, our weight, the circumference of our chest, nor what conditions our blood should fulfil, [nor] the number of litres of urine we excrete in 24 hours!! ... It is enough to open any book on physiology written in French (almost always in French) and copy. What does it matter? Neither our climate, nor our diet, nor our customs in general can alter in Mexico the results obtained in Paris!!⁷⁴

Vergara Lope was a man of firm convictions who may well have made a myth of his experimental work. He gave ideological and political weight to his science. Perhaps one cause of his initial success was the exaggerated nationalism that so greatly motivated him but, paradoxically, may later have caused his undoing. Nationalism in science is a frequent phenomenon because science is a human activity.

Contemporary historians of science recognize that the development of science depends upon many factors in the countries where it takes place; for example, cultural and social conditions, certain characteristics such as religion, language, type of government and the stratification of social classes, the value that the population grants to science and the ease or difficulty with which people can accede to it, etc. (Regarding nineteenth-century medical science, for example, we speak of “German chemistry”, “French physiology” or “English physiological chemistry”.) In fact, there are studies that relate such factors as nationality to the winners of the Nobel Prize.⁷⁵

In *Nationalism and internationalism in science*, Elisabeth Crawford mentions that in the 1830s Alphonse de Candolle, the Swiss naturalist, was one of the first to reflect upon the topic of science and nationalism. His work was serious, though he assumed, *a priori*, that

⁷³ Vergara Lope, *La anoxiemia barométrica*, op. cit., note 22 above, p. 53.

⁷⁴ D Vergara Lope, ‘Hematología de las altitudes en sus relaciones con la clínica y la terapéutica’, *Revista Quincenal de Anatomía Patológica y Clínicas Médica y Quirúrgica*, 1896, 1 (11): 360–1.

⁷⁵ See, for example, Elisabeth Crawford, *Nationalism and internationalism in science, 1880–1939*, Cambridge University Press, 1990, and L W Home and S G Kohlstedt (eds), *International science and national scientific identity*, Dordrecht, Kluwer Academic, 1991.

“those belonging to the Asian, African and Native American races have remained completely outside the scientific movement”.⁷⁶ Although it is said that science is universal in character, in strict terms this is not true. Many characteristics that we could qualify as “national” determine the development of science in each nation. It is clear that national differences exist in the development of science. During Vergara Lope’s life, these national differences influenced Mexican science, as well as the thought and actions of the man himself. Had he been a scientist today, Vergara Lope would have been measured by his peers throughout the world and might have belonged to the international scientific élite. However, his circumstances were different.

The evolution of science and the evolution of the social history of science cannot be measured on the same scale. The fact remains that, despite his many works and undeniable contribution to Mexican physiology, Vergara Lope has remained in obscurity. A reason for this, in addition to the possible explanations that we have presented in this study, could be that then—as now—the science that was carried out in developing countries was considered “peripheral”, and people thought that “true” scientific knowledge was transplanted or imported from developed countries. This article also evokes the ideas of colonialism in science and in the history of science in Mexico. There are very interesting cases of this phenomenon, especially in relation to French science. Under the flag of humanitarianism and through the application of the benefits of medicine, real intentions of colonization did, in fact, exist.⁷⁷

In Peru, Carlos Monge Medrano also made a nationalistic defence of the adaptation to high altitudes and—almost thirty years later—described the same phenomena that Vergara Lope had found.⁷⁸ However, Monge’s personality and the circumstances of the period in which he lived brought him worldwide fame.⁷⁹

Part of the basis of modern Mexican physiology is the high-altitude branch, and Vergara Lope was unquestionably the pioneer in this field. At the same time as he applied the experimental method in the strictest sense of the term, he also incorporated the use of instruments and mathematics in laboratory research.

When all is said and done, however, it was his nationalism that finally trapped him, and it may be that his objectivity vanished in the face of his obsession with vindicating the Mexican race and the Mexican high plateau. Nevertheless, his field continues as a research subject in many prestigious centres around the world. Several aspects of the physiological response of humans to moderate altitudes are still largely unknown and constitute a priority for a considerable number of people in many countries. Vergara Lope’s general idea of adaptation to altitude is correct, as is his sense that human life at moderate altitudes was not necessarily doomed. Daniel Vergara Lope Escobar was indeed the first scientist to demonstrate the mechanism of adaptation to high altitudes, though the world has taken little notice of his work.

⁷⁶ Crawford, *ibid.*, p. 12.

⁷⁷ The situations described in the following works illustrate the Mexican case very well, though they refer to other countries. P Petitjean, C Jami and A M Moulin, *Science and empires: historical studies about scientific development and European expansion*, Dordrecht, Kluwer Academic, 1992; M A Osborne, *Nature, the exotic and the science of French*

colonialism, Bloomington, Indiana University Press, 1990.

⁷⁸ Carlos Monge Medrano, *La enfermedad de los Andes: síndromes eritrémicos*, Lima, Americana, 1928.

⁷⁹ A C Rodríguez de Romo, ‘Daniel Vergara Lope and Carlos Monge Medrano: two pioneers of high altitude medicine’, *High Altitude Medicine and Biology*, 2002, 3 (3): 299–309.