Mountain Medicine and Physiology: A Short History

MICHAEL WARD

(*Plates* 76, 77)

The story of man's attempts to climb higher and higher by his own unaided afforts is one of the most colourful and exciting in the history both of mountaineering and of medicine and physiology. The mountaineer at altitude acts as a model for those at sea-level with oxygen lack due to chronic heart and lung disease, and even the hill-walker, exercising for hours on end over consecutive days, may develop pitting oedema of the ankles, which is also found in a number of medical conditions.

At extreme altitude the mountaineer is exposed to some of the harshest conditions on earth, with temperatures of −50°C, winds gusting to 100mph and more, and – with the barometric pressure a third of the sea-level value on the top of Everest (8848m) – it is surprising that he can survive at all. That he is able to do so is due to a remarkable series of adjustments which enable the internal environment in which his cells live to remain constant. Claude Bernard (1813–78), Professor of Physiology in Paris, first drew attention to this stability: and it is fitting that Paul Bert, the founding father of altitude physiology, followed him in this, the most prestigious chair of natural philosophy in France.

Observations on the effects of high altitude date back many centuries. The Silk Road, which joined the civilizations of the Mediterranean with those of China and India, is the world's oldest, longest and most dangerous land trade route, and it is not surprising, therefore, that the first documented account of mountain sickness should come from Chinese sources, between BC37 and 32. This describes travelling south-west from Yarkand (Shache) to Afghanistan, passing the Great and Little Headache mountains, and alludes to vomiting in both man and cattle.[1] There is a later description of mountain sickness in the accounts of the well-known Chinese traveller Fa-Hsien (AD399–414), who travelled in the same area. He describes what may well have been a case of high-altitude pulmonary oedema, while crossing a high pass, for the victim frothed at the mouth and later died.

Considerable altitudes were also reached in Central and South America, for well-built pre-Columban structures have been found near the summit of Llullaillaco (6712m). These were not permanent dwelling places but were probably associated with mountain worship, since an Inca body has been found at a similar altitude. There is as yet no record of an Asian highlander reaching a comparable altitude until the end of the 19th century; the impetus for the

exploration of the world's peaks, passes and glaciers had to await European and other western mountaineers rather than the indigenous inhabitants.

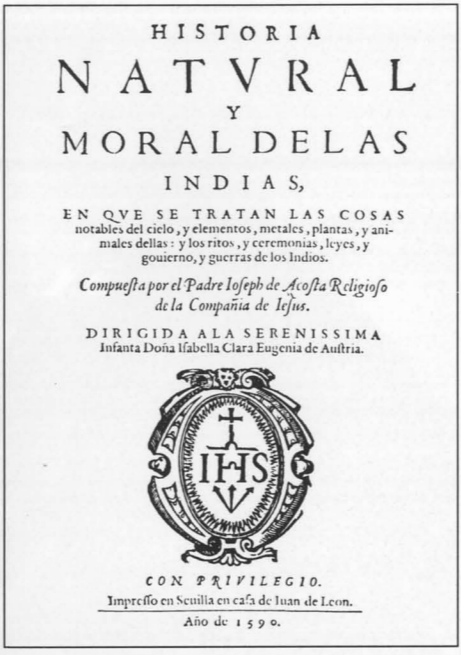
The clinical features of mountain sickness were described for the first time (in Spanish) by a Jesuit priest, Father Joseph de Acosta. His account is compelling and graphic, for he describes the 'casting up of meate, *fleugme*, and choller both yellow and greene'.[2] The local South American names for mountain sickness were Puna, Seroche, Mareo and Veta, and the cause was thought to emanate from the metal antimony. In some regions the vapours of rhubarb, primroses and roses were blamed. De Acosta, in an inspired deduction, thought that the symptoms were due to the 'thin air'.

In Europe the idea that air had weight and therefore exerted pressure on the earth's surface had to wait until the Renaissance for its full realization. It was Torricelli, a pupil of Galileo, who realized that the force of a vacuum was due to the weight or pressure of the atmosphere. An experiment, conceived by Pascal, proved that atmospheric pressure was less on the summits of high peaks, and this of course is the central problem of high altitude: for, as the atmospheric pressure is lowered, so is the oxygen pressure, and less oxygen gets driven through the lungs and less arrives at the cells.

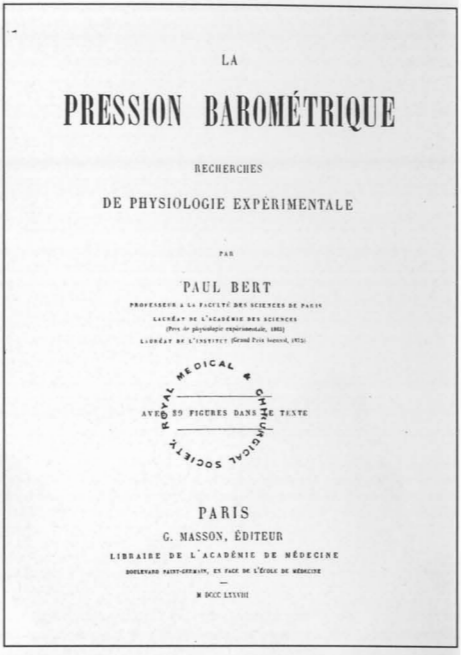
In the 17th century, rumours of Nestorian Christian colonies led to Rome sending missionaries to Central Asia and Tibet. Probably the first European to enter Tibet was Father Andrade, a Jesuit priest, who crossed the Himalaya by the Mana Pass (5450m) in 1624. He, however, was more concerned with hypothermia than with hypoxia. Thirty years later, Fathers Gruber and D'Orville crossed the Tibetan plateau from north to south, visited Lhasa and then crossed the Himalaya. They commented, 'Man cannot breathe in the Langur mountains (Himalaya) because the air is so subtile.' There is a later reference in 1739, by Father Belligate, to the 'deleterious exhalations' found in the mountains. This may have been a reference to La-Drak, 'The Poison of the Pass', which was considered by Tibetans to be exhalations of mischievous Gods who caused earthquakes and avalanches, in addition to mountain sickness.

Mountain sickness was called 'Yen Chang' by the inhabitants of the Koko Nor region, and 'Chang Chi' in Szechuan. Both expressions mean a pestilential vapour thought to be given off by the large quantities of rhubarb that grow in the mountains. Another term was 'Tutek', described by Sven Hedin as occurring in gold mines in North Tibet. This appeared to be a long-standing and often fatal condition in which the victim's body swelled up, his lips turned black and mental disorder occurred. It is possible that this was chronic mountain sickness (Monge's Disease) which was first described by the South American physician Carlos Monge in 1925.

The exploration of the Himalaya began in earnest in the early part of the 19th century, and Paul Bert started his study of the effects of barometric pressure at this time. He collected accounts of altitude illness from all over the world and, in addition to his own work in decompression chambers, became interested in the opportunities available from balloon ascents for the study of altitude physiology. The first 350 pages of his classic work *La Pression Barométrique*, published in 1878[3] are the most authoritative early account of the history of the effects of decreased barometric pressure. His work did not go


HISTORIA
NATVRAL
Y
MORAL DELAS
INDIAS,
EN QVE SE TRATAN LAS COSAS
notables del cielo, y elementos, metales, plantas, y animales dellas: y los ritos, y ceremonias, leyes, y gouierno, y guerras de los Indios.
Compuesta por el Padre Ioseph de Acosta Religioso de la Compañia de Iesus.
DIRIGIDA A LA SERENISSIMA
Infanta Doña Isabella Clara Eugenia de Austria.
IHS
CON PRIVILEGIO.
Impresso en Sevilla en casa de Iuan de Leon.
Año de 1590.

76. *The title page of Joseph de Acosta's* Historia Natural y Moral de las Indias, *1590.* (From Bodleian Library, Oxford, by permission) (p 191)


LA
PRESSION BAROMÉTRIQUE
RECHERCHES
DE PHYSIOLOGIE EXPÉRIMENTALE
PAR
PAUL BERT
ROYAL MEDICAL & CHIRURGICAL SOCIETY
AVEC 89 FIGURES DANS LE TEXTE
PARIS
G. MASSON, ÉDITEUR
LIBRAIRE DE L'ACADÉMIE DE MÉDECINE

77. *The title page of Paul Bert's* La Pression Barométrique, *1878.* (From Library of the Royal Society of Medicine, London, by permission) (p 191)



78. *Fünffingerspitze.* (C Douglas Milner) (p 204)

uncriticized, particularly by Angelo Mosso, Professor of Physiology at Turin, another considerable physiologist who was responsible for the construction of the Capanna Regina Margherita on the Punta Gnifetti (4556m) in the Monte Rosa massif. Rebuilt recently, this still serves as a hut and a laboratory, and is the highest hut in the Alps. Professor Mosso's book *Life of Man on the High Alps*[4] includes the first dramatic clinical description of high-altitude oedema and also an autopsy report.

The early volumes of journals published by the Alpine Club, starting with *Peaks, Passes and Glaciers* in 1859 and continuing with the *Alpine Journal*, contain a number of articles on mountain sickness. Spinal anaemia, dry air and fatigue were all implicated, and Longstaff, who made outstanding contributions to mountain exploration in the Nanda Devi region, on Gurla Mandhata, and who discovered the Siachen glacier in the Karakoram, was the first British mountain scientist to write a comprehensive treatise on mountain sickness. This was published in 1906.[5]

The end of the 19th century and the start of the 20th century saw the discovery of an increase in red blood cells at altitude. There were, in addition, three expeditions of outstanding importance. These took place in a period when there was great controversy over how the lungs worked: whether oxygen was secreted by the lungs or whether it diffused from the air through the lung walls into the blood vessels as a result of the force of atmospheric pressure. Ascent to high altitude would help to solve these problems.

Edward Whymper[6] in 1879 organized an expedition to South America, to observe the effects of low barometric pressure and 'to attain the greatest possible height in order to experience it'. He made many cogent observations on mountain sickness (as well as on other fields of science), and was elected a Fellow of the Royal Society of Edinburgh in 1894, despite his lack of formal scientific training.

The second expedition was that of Conway[7] in the Karakoram, and he acknowledged Whymper's work in South America, calling it a model of its kind. His party traversed the Biafo and Baltoro glaciers and he took recordings of his pulse at regular intervals by means of a pulse sphygmograph. In one reading, at 6100m, his heart rate was exactly half that taken at similar altitudes a few hours before and after. This may have been an incident of transient 2:1 heart block and it focused attention on the heart at high altitude.

The third expedition was that of the Duke of the Abruzzi.[8] His party reached 24,600ft (7500m) on Bride's Peak in the Karakoram and suffered little or no discomfort. However, he gives the first description of high-altitude deterioration, recording that 'the atmosphere of this height did work some evil effect revealing itself only gradually after several weeks of life above 17,500ft'. Later he made the categorical statement that 'perfect adaptation to the surroundings is not possible above 17,500ft', which was confirmed on the Silver Hut expedition to the Everest region in 1960–61. The ascent to 24,000ft amazed many physiologists, for it was thought that not enough oxygen could diffuse through the walls of the lungs at the low barometric pressure of high altitude, particularly when exercising, as such large amounts of oxygen are needed by the muscles.

The arguments in favour of diffusion put by Barcroft of Cambridge, and in favour of oxygen secretion by Haldane at Oxford, ranged over many years. In point of fact the early work in favour of diffusion had been carried out by Krogh in Copenhagen at the turn of the century, but had been 'lost' only to be rediscovered in the 1930s. Eventually Barcroft showed conclusively that diffusion occurred. He did this by having the main artery of his arm exposed by dissection and the oxygen pressure in the blood estimated at ever-increasing altitude. This was always lower than the pressure in the lungs, indicating that diffusion not secretion (when the pressure in the arm artery would have been higher than in the lung) had occurred.[9] The estimation of 'blood gases' is now routine in hospital.

In 1921, after years of prevarication, the government of Tibet gave permission for a British party to explore the northern Tibetan approach to Everest, since the more direct Nepalese southern approach was not feasible politically.

The individual who knew most about the geographical and physiological problems of altitude was Alexander Kellas, a lecturer in chemistry at the Middlesex Hospital Medical School. Before he went on the 1921 Everest reconnaissance he wrote a paper entitled 'A consideration of the possibility of ascending Mt Everest'. This was published in a little-known continental journal, following a meeting in Monte Carlo, and was probably never read by scientists or mountaineers in the UK. Luckily copies of his manuscript were deposited in the archives of both the Alpine Club and the Royal Geographical Society. An appraisal of this article can be found in the *Alpine Journal*.[10] Kellas's insight in asking the correct questions is uncanny and, although a number of his calculations were inevitably wrong, the paper was a landmark in high-altitude physiology. Had it been published in the UK, it might, at the very least, have prompted a careful examination of the scientific factors involved in attempts on Mount Everest.

The series of expeditions to Mount Everest between 1921 and 1938 gives a very important insight into the problems of high altitude and cold. The harsh clinical realities of oxygen lack were set out in each of the Everest books, yet there seems to have been a reluctance to accept the facts. Another important factor was the conflicting evidence from the use of supplementary oxygen. It is easy now, with hindsight, to understand these, but at the time it was not at all clear why some appeared to climb as well at great altitude without supplementary oxygen as with it. In practical terms, a height of 28,000ft (8500m) had been reached in 1924 and, since then, no one had gone any higher either with or without supplementary oxygen.

This was the position at the end of the Second World War. On Everest the post-war era started in the autumn of 1950 with the visit of the Houston party to Sola Khumbu, to which Tilman had a late invitation, the first Europeans to visit the Nepalese side of Everest. From the highest point that he reached on the Khumbu glacier, at Kala Pattar (5554m), Tilman took a photograph of Everest but was very pessimistic about the chances of a route. His pessimism was countered by research in the Royal Geographical Society, where good ground and aerial photographs, taken between 1933 and 1947, showed each section of

a possible route up which the mountain was first climbed in 1953. Also important was a 1:50,000 'running' map, drawn by H F Milne of the Drawing Office at the Royal Geographical Society between 1933 and 1945, based on Spender's survey work on the north side of Everest in 1935, aerial photographs taken on the 1933 flight over Everest and other sources. On this map each detail of the eventual route – the Lhotse Face, Geneva Spur, South Col and Ridge and South Summit – were meticulously drawn, with spot heights. All this information was obtained before Shipton, the eventual leader of the 1951 Everest reconnaissance, was even aware that any expedition to Everest was planned.[11]

The provenance of the photographs and Milne's map will be discussed in the *Geographical Journal*.[12] In essence, however, the Holy Grail of Himalayan and mountain exploration, a possible new route up Everest from the south, was 'discovered' without setting foot outside London, always accepting that no route on any peak is feasible until one's nose has been rubbed against the rock and ice of which it is comprised.

In early 1951, too, Dr Griffith Pugh of the Medical Research Council started on the practical physiological problem of the ascent of Everest. As well as suffering from severe oxygen lack, it became apparent that mountaineers at great altitude were starved, severely dehydrated and suffering from cold injury, and some had had strokes. It was a daunting clinical picture that could be overcome only by adequate supplementary oxygen and attention to the detail of providing adequate insulation, good stoves and fuel. The problem was soon apparent, but the solution would require scientific work in the field at an altitude of 5200–5500m, as decompression chamber studies would be inadequate.

After the Everest reconnaissance in the autumn of 1951 had confirmed the existence of the route already identified by photographs and map, a training expedition to Cho Oyu in the spring of 1952 was led by Shipton, while the Swiss attempted Everest in both the spring and the autumn. Pugh joined the Cho Oyu party and, with Tom Bourdillon and two others, worked in a tented laboratory on the Menlung La at 5800m about 24km south of Cho Oyu. Pugh's 'Report on the Cho Oyu Expedition' was published by the Medical Research Council within weeks of his return to the UK in the early autumn of 1952: it revolutionized high-altitude climbing. It determined the organization of the 1953 Everest Expedition – started by Shipton and carried on by Hunt when he was made leader in late 1952. The flexibility provided by adequate supplementary and sleeping oxygen (used often for 18 hours out of the 24 above the Western Cwm) allowed mistakes in planning and execution to be overcome, and contributed overwhelmingly to the good general condition of the climbers. It is no coincidence that by 1960 every 8000m peak had been climbed following the precepts of this report. It is now in the archives of the Alpine Club.[13]

Following the first ascent of Everest by Hillary and Tenzing in 1953 using supplementary oxygen, there was still the tantalizing possibility that the mountain might be climbed without, for, after spending 40 days in a decompression chamber during Operation Everest I in 1946, Houston (in Florida) had exercised on a bicycle ergometer without using supplementary

oxygen at an altitude higher than the 'summit of Everest'. However, the first ascent of Everest without oxygen had to wait until 1978.

The next landmark in field investigation was the Himalayan Scientific and Mountaineering (Silver Hut) Expedition to the Everest region in 1960–61, which involved the use of polar techniques. The expedition had Pugh as scientific leader, whilst the overall leader was Hillary who returned to New Zealand during the winter months when the scientific work was completed at 5800m. The results obtained during this period have been basic to understanding the chronic oxygen lack at altitude, and this carries over to other fields of medicine. This expedition also highlighted a number of diseases due to altitude, in particular vascular episodes, and high-altitude deterioration associated with cold injury.[14]

In 1960, in the US, Houston wrote a classic paper on high-altitude pulmonary oedema.[15] This condition had been described previously by Ravenhill, a South American mining doctor, in 1913, but the journal in which his article was published was rather obscure and knowledge of the condition was not widely disseminated. Houston's paper was the starting point of many investigations into fluid shifts in the body due to exercise and altitude.

In the UK during this period the increase in outdoor activities, particularly in hill country, had led to a number of unexplained deaths. As had occurred on Everest, Pugh again solved this problem by laboratory and field work. Essentially, the combination of wind, movement and wetting could and did lead to the hill-walker being exhausted and effectively without insulation, and thus inevitably hypothermic.

The next important milestone was the ascent of Everest by Habeler and Messner in 1978[16], without supplementary oxygen. A vitally important factor in explaining this feat, which had seemed impossible to so many mountaineers and respiratory physiologists, was the realization that the barometric pressure, and hence the oxygen pressure, on Everest was higher than had been previously calculated. This is because in the altitude range 6–16km (Everest is 8848m) there is a pronounced bulge in the barometric pressure near the equator in winter and summer. Since the latitude of Everest is 28°N, the pressure at the summit is considerably higher than it would be for a hypothetical peak of the same height near the Poles. The cause of the pressure bulge is a large mass of cold air in the stratosphere above the equator, brought about by a combination of complex radiation and convection phenomena. Also, the barometric pressure is higher in summer than in winter, and the first winter ascent of Everest without supplementary oxygen (by a Sherpa, Ang Rita) took place only in December 1987.

One of the most important scientific expeditions ever mounted was the American Medical Research Expedition to Everest in 1981.[17] It was led by West, a member of the Silver Hut team of 1960–61. For the first time physiological measurements were made at the summit, and a large number of investigations was completed. Perhaps the most controversial and potentially important finding was that of diminished mental function after a long stay at altitude.

Although sophisticated field studies are now possible and have been

carried out by workers of many nationalities, there are still some important investigations too dangerous to be carried out in the mountains, such as estimates of the pressure in the chambers of the heart. These can be completed in a decompression chamber, and in 1985, after five years' preparation, Operation Everest II – a study at the US Army Department of Environmental Health at Natick, Mass – was completed by Houston and his colleagues. Volunteers were decompressed over 40 days and nights to the 'summit of Everest', and many of the findings of AMREE 1981 were confirmed and extended.[18]

One of the most obvious and important effects of high altitude is on breathing, and disordered or periodic breathing has been described, both at altitude and in desperately ill patients at sea-level. Tyndall's book *Glaciers of the Alps*, published in 1860[19], contains the first altitude reference, and Tyndall, whilst resting on the summit of Mont Blanc, was observed by his companion not to have breathed at all for a considerable period. Previous to this, in 1781, John Hunter[20], the father of scientific surgery, had written a crisp, accurate and laconic account in his case notes, now kept in the library of the Royal College of Surgeons of England. He writes '. . . but his breathing was very particular: he would cease breathing for twenty to thirty seconds and then begin to breathe softly, which increased until he breathed extremely strongly or rather with violent strength, which gradually died away until we could not observe that he breathed at all.' The first visual record of periodic, or Cheyne-Stokes, breathing was made by Angelo Mosso on a revolving drum at the Capanna Regina Margherita, and this condition is being intensively investigated in terms of control theory.

Another 'abnormality' of breathing, noted at altitude, is that whereas newcomers are breathing deeply and often, even when taking minimal exercise, the high-altitude resident is breathing quite easily. This is because the acclimatized resident has a blunted response to oxygen lack, which at first sight should produce less oxygen for the cells. This apparent contradiction may be associated with changes at cellular level, possibly the most important factor in acclimatization to oxygen lack.

Indeed, Paul Bert himself in 1878 wondered if the high-altitude dweller functioned better than the sea-level visitor. 'Just as the Basque mountaineer furnished with a piece of bread and a few onions makes expeditions which require of the members of the Alpine Club who accompany him the absorption of a pound of meat, so it may be that the dweller in the high places finally lessens the consumption of oxygen in his organism . . .'[21]

Surprisingly, then, the mountaineer, indulging in his arcane pursuit, thought at one time 'to be perfectly useless even to those that did it', now finds himself to be a useful individual, in particular to those who, due to illness, cannot climb at all.

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