Mountain Sickness

The varied and subtle symptoms of this potentially lethal disorder humble many who scale the summits.
But the problem is often preventable

by Charles S. Houston

On New Year’s Eve in 1960, I received a call from a young man who had left his sick companion high in the mountains near Aspen, Colo., to ski out for help. A rescue party was assembled, and the following evening the patient was brought to a hospital for treatment of what I anticipated from his friend’s description of the problem would be pneumonia. Instead the young man had an accumulation of fluid in both lungs that was unlike the inflammation seen in pneumonia.

Since this finding was unusual, a distinguished cardiologist urged me to publish my observations. The resulting short article in the New England Journal of Medicine brought hundreds of letters describing similar altitude-related illnesses that had been characterized as pneumonia. The discovery of what seemed to be a new form of mountain sickness—subsequently named high-altitude pulmonary edema—quickened my long-standing interest in mountain climbing and the medical problems associated with high altitudes. In 1936, as a medical resident, I had accompanied a team of climbers to the Himalayas where I had seen, but failed to recognize, my first case of altitude sickness.

High-altitude pulmonary edema and other symptoms of illness produced by high altitudes cause significant medical problems. Today record numbers of people visit mountains to climb, ski, walk or simply vacation. In recent years rapid transportation and better equipment have made mountain climbing more popular. Between 1903 and 1912, for instance, only 42 climbers attempted to reach the summit of 20,400-foot Mount McKinley in Alaska. None was successful. Between 1988 and 1990, 2,923 attempted the climb; 1,659 made it. Accordingly, the number of victims of high-altitude pulmonary edema and associated illnesses has increased. Fourteen percent of the fatalities on Mount McKinley have been attributed to altitude sickness.

Mountain sickness is caused primarily by a lack of oxygen, or hypoxia. Atmospheric pressure decreases as one moves away from sea level, and because the percentage of oxygen in air remains constant, the concentration of oxygen is decreased. Lower levels of oxygen initiate a series of potentially fatal physiological changes.

Yet prolonged exposure to altitude, or, conversely, to sea-level conditions that cause a lack of oxygen may produce adjustments called acclimatization. This process enables people to survive with levels of oxygen that would otherwise cause serious problems. Understanding the many dangers of hypoxia, the different forms of altitude illness and the process of acclimatization is crucial to safety on the stunning mountains that crown the earth.

Although only recently defined as a form of altitude sickness, pulmonary edema at high altitudes is far from new. In A.D. 403 a Chinese archivist, Hui Jiao, traveled the Silk Route and recorded his traveling companion’s illness: “The wind was chilling to the bones on the shady north side of the Lesser Snowy Mountains. Hui Jiao was in a serious condition, frothing at the mouth, losing his strength rapidly and fainting away now and then. Finally he dropped dead on the snowy ground.”

One hundred and fifty years later Mogul chieftain Mirza Muhammad Haidar described the often devastating condition that affected his troops campaigning on the Tibetan Plateau (at 13,000 to 15,000 feet). The symptoms ranged from weakness and shortness of breath to hallucinations, culminating in coma and often death. At the end of the 16th century, Jesuit priest José Acosta wrote a similar description while he was crossing a high pass in the Andes.

Hui Jiao, Haidar and Acosta could not know what caused this illness, because the nature of the earth’s atmosphere was not understood until the mid-17th century. At that time, a series of experiments conducted by Gaspar Bertí, Evangelista Torricelli and Florin Périer showed that the atmosphere did have weight and that its pressure decreases as the altitude increases.

In the 18th century people began climbing mountains for pleasure, and physicians started to define clinically the physiological effects of lowered atmospheric pressure. In 1786 climbers ascended Mont Blanc, the highest peak in Europe at 15,771 feet. During the next decade, Horace-Bénédict de Saussure described how his heart and respiration were affected by altitude. Soon oxygen was identified, and its importance for supporting life as well as combustion was demonstrated. But the connection between hypoxia and mountain sickness remained unrecognized.

The golden age of alpine climbing began in the 1850s, when British doctor Albert Smith undertook a career lecturing about his ascent of Mont Blanc. Thousands of people went into the mountains, and in the next three decades all the alpine summits were reached. A few explorers turned to the Himalayas and the Andes. Balloons, first flown a century before, also became fashionable, and the daring went high enough to suffer from altitude.

Charles S. Houston is a physician who has loved mountains ever since his first alpine ascent in 1925. In 1936 he climbed in the Himalayas, and in 1938 he led the first American expedition to K2 (at 28,251 feet). After receiving his M.D. from Columbia University, Houston entered the U.S. Navy, where he served as a flight surgeon, specializing in high altitude. Houston, who taught internal medicine at the University of Vermont, continues his altitude-related research.

Mountaineer tackles Mount Fitzroy (at 11,070 feet) in Patagonia. By ascending slowly and allowing for acclimatization, experienced climbers can avoid some of the perils of mountain sickness.
The words “mountain sickness” began to appear in the popular and medical literature. Stories, often exaggerated, described the symptoms that plagued climbers and some animals, but there was little agreement about their cause. Failure to mention the miserable effects often raised doubts that a summit had been reached.

In the last decades of the 19th century, the work of two physicians clarified the relation between thin air and mountain sickness. Paul Bert conducted studies at simulated altitudes in an iron decompression chamber and measured the carriage of oxygen by hemoglobin. After showing that blood contained less oxygen at altitude than it did at sea level, he took himself to a simulated 21,000 feet—while breathing oxygen from a leather bag. Because no symptoms appeared, he concluded that lack of oxygen, rather than lack of pressure, caused mountain sickness.

Bert’s contemporary, Angelo Mosso, studied men on top of 15,203-foot Monte Rosa in Italy as well as in a decompression chamber. He too decided that hypoxia caused mountain sickness but argued that the lack of carbon dioxide resulting from overbreathing was more important.

The imperatives of aviation during...
the two world wars and a growing interest in mountain sports increased people’s understanding of hypoxia. Studies showed that there are several different forms of mountain sickness—one an unpleasant, but minor problem, others more serious and potentially fatal. Symptoms depend on which parts of the body are most susceptible.

The brain is extremely vulnerable. On average, the human brain receives 10 to 15 percent of the heart’s output and uses 15 to 20 percent of the oxygen consumed by the body. The cerebral cortex, where the most complex mental activity takes place, is the most demanding region. It is not surprising, then, that hypoxia affects the higher centers of the brain first, including judgment. Indeed, the effects of hypoxia resemble those of alcohol.

Headache is the most prominent symptom of mountain sickness, but its cause remains unclear. One explanation may lie in the response of a sensitive membrane called pia mater, which covers brain tissue and blood vessels. As arterial oxygen levels fall, blood flow to the brain increases. Consequently, distended vessels or swollen brain tissue may press on the surrounding membranes, causing headache. At the same time, the lack of oxygen stimulates increased breathing, which pumps carbon dioxide out of the lungs and blood. Lowered carbon dioxide, in turn, causes a decrease in blood flow to the brain.

Whether blood flow to the brain ultimately increases or decreases depends on the balance between hypoxia and hypocapnia (decreased carbon dioxide) as well as on the sensitivity of the receptors that govern blood flow. This sensitivity varies from individual to individual, which may explain why reports of the severity of headache differ greatly and why studies of cerebral blood flow at altitude often produce contradictory results. The nausea, vomiting and disturbed sleep so typical of mountain sickness may be the result of altered blood flow to the midbrain, where these functions are controlled.

Hearing, smell and taste are not affected by altitude, but appetite usually decreases, in time leading to weight loss. It is unclear whether such loss results from malabsorption or simply from a smaller caloric intake.

Clearly, the effects of hypoxia are quite varied. The signs and symptoms differ depending on the altitude reached, the speed of ascent and other influences. What may seem a rather unpleasant but mild illness can change rapidly to one that is life-threatening. Not uncommonly, for example, a visitor to a mountain resort will feel a headache and general malaise and will soon develop shortness of breath and a cough. These symptoms can lead to coma or hallucinations and, if not cared for properly, death.

Although these symptoms form a continuum, for convenience I will describe them as separate entities. The most common form of illness is called acute mountain sickness, and it affects a quarter of the visitors to mountain resorts. The signs are usually those described above: headache, nausea, vomiting, anorexia and lassitude. Seldom fatal, acute mountain sickness can become serious.

The affliction of my patient in Aspen, high-altitude pulmonary edema, is less frequent but more dangerous than acute mountain sickness. Studies have shown that most people going to even moderate altitudes, such as 8,000 feet, develop some fluid in the tissue that separates the alveoli, or air sacs, from the capillary blood vessels. This fluid is usually promptly reabsorbed.

If the fluid accumulates within the alveoli, however, passage of oxygen from lung to blood is impaired. At this point, hypoxia worsens, and more fluid leaks into the air sacs. The victim can literally drown in his or her own juices. The symptoms are increasing shortness of breath and an irritating cough that produces frothy, blood-tinged sputum.

More serious than high-altitude pulmonary edema is high-altitude cerebral edema. In this form of sickness, which can occur at heights as low as 9,000 feet, the central nervous system is affected: parts of the brain become waterlogged. Early warning signs include ataxia, manifested by a staggering drunken walk or by difficulty in performing fine-motor skills. These changes are attributed to swelling of the cerebellum, the area of the brain that controls balance. Mental confusion and hallucinations are also common. If untreated, cerebral edema can cause death.

At the end of the physiological continuum lies chronic mountain sickness, an uncommon problem affecting a few people who live permanently above 12,000 feet. Victims experience fatigue, palpitations, chest pain and swelling of the ankles, and they develop an overabundance of red cells and blood clots in their veins and lungs. Going to low altitude corrects the often-fatal affliction.

Above heights of 10,000 feet, changes can also occur in the eyes. Because the large supply of oxygen that the rods require is no longer readily available, vision in dim light is decreased by 50 percent. In addition, above 14,000 feet people may develop tiny bleeding spots in back of their eyes. These retinal hemorrhages are usually unnoticed. Researchers have been unable to determine whether the hemorrhages have prognostic or diagnostic importance. Some believe they reflect bleeding elsewhere in the body, a rather unattractive thought for climbers. Those who contend that repeated or prolonged exposure to severe hypoxia may leave permanent brain damage blame it on similar bleeding in the brain.

Intercise, seemingly contradictory changes take place as the body responds to hypoxia. The depth and rate of breathing increase, bringing more air deep into the lungs, raising alveolar oxygen pressure and reducing blood levels of carbon dioxide. This response, however, creates a crisis. Hypoxia can and must be relieved by hyperventilation. Yet the pH of the body must also be maintained. Because this balance is brought about by preserving a certain concentration of carbon dioxide, hyperventilation threatens homeostasis.

Faced with this dilemma, the body compromises by increasing respiration enough to elevate alveolar oxygen and by excreting bicarbonate to offset the alkalosis caused by dwindling blood levels of carbon dioxide. Success in balancing these two conflicting demands determines the effectiveness of acclimatization as well as whether or not an in-
The Spectrum of Altitude Sickness

Chronic mountain sickness affects people who lose their tolerance to high altitude or who fail to acclimatize. It is characterized by fatigue and chest pain as well as by an increase in red blood cell count and, sometimes, heart failure. Chronic mountain sickness can be alleviated by descent to sea level.

High-altitude cerebral edema can occur at 9,000 feet but is much more common at altitudes above 10,000 feet. Characterized by mental confusion, hallucinations and drunkenlike walking, high-altitude cerebral edema often develops within 36 hours after arrival at high altitude.

High-altitude pulmonary edema routinely occurs above 9,000 feet, although it afflicts some people at lower altitudes. The symptoms— including shortness of breath, severe cough, blood-tinged sputum, headache, lethargy and mild fever—usually develop after 36 or 72 hours at altitude.

Acute mountain sickness affects 15 to 17 percent of people who climb to 8,000 feet or higher too rapidly. It is characterized by headache, fatigue, shortness of breath, disturbed sleep and, sometimes, nausea. The illness rarely requires any treatment other than descent.

Individual is stricken with altitude illness.

The dual control of breathing causes an interesting phenomenon—an irregular fluctuation as control shifts between centers in the midbrain responsive to carbon dioxide and blood pH and the carotid bodies, small collections of cells in the neck that are sensitive to oxygen. The result is an erratic pattern called periodic, or Cheyne-Stokes, breathing that is common above 9,000 feet and universal at higher altitudes. Typically a period of rapid, increasingly deep breathing is followed by shallower breathing until breathing stops completely for an alarming time (between eight to 10 seconds), before the cycle repeats. Periodic breathing is more pronounced during sleep, and so average oxygenation falls when one is asleep.

Another early response to hypoxia is an increase in heart rate and stroke volume, which propels more oxygenated blood throughout the body. Concurrently, there is a temporary shift of fluid from blood into tissues, concentrating hemoglobin and thus enabling the heart to deliver more oxygen in each stroke. The increased cardiac output subsides in a week or so, but the increased ventilation persists for the most part throughout the stay at altitude.

Production of red blood cells is stimulated by an immediate increase in erythropoietin—a hormone that acts on bone marrow. Other primary or secondary changes occur in many hormonal systems and in the activity of the sympathetic nervous system. There is little doubt that hypoxia also disturbs electrolyte and water balance. It leads to vasoconstriction, water retention and changes in the permeability of cell membranes as well as disturbed kidney function.

While we understand many of the changes the body goes through in its response to falling concentrations of oxygen, puzzles remain—particularly on the cellular level. The precise pathophysiology of hypoxia has yet to be fully explained.

One theory holds that hypoxia causes a reversible breakdown in the function of an energy-intensive ion channel called the sodium pump. This pump maintains normal levels of sodium and potassium within each cell. Because the sodium pump uses as much as 20 percent of the body's total oxygen uptake, it is not surprising that it may falter when oxygen is in short supply.

According to this theory, when the system fails, sodium accumulates within the cell and potassium leaks out, disturbing water balance and causing edema. The cells in which the pump fails most dramatically are the ones most affected by hypoxia. This failure in turn affects which form of altitude sickness develops. Recent studies also suggest that calcium channels are altered by hypoxia, and it may be that the failure of still other pump systems contributes to mountain sickness.

For reasons that remain unclear, hypoxia also seems to increase the contractility of the small arterioles in the lungs. This resistance causes an increase in pulmonary artery pressure. Consequently, the vessels become distended, stretching the endothelial lining and bringing about the release of biologically active substances, called eicosanoids, or kinins. Some eicosanoids increase vascular leakiness and platelet aggregation, or clumping, whereas others decrease these effects. The strength of the response determines whether or not lung edema results.

Increased pressure in the pulmonary arteries is also thought to stretch and even to rupture the tight junctions between endothelial cells. Together with the action of eicosanoids, the widened junctions permit leakage of plasma and red blood cells into the interstitial and alveolar spaces. This chain of events could explain why high-altitude pulmonary edema is so different from the edema caused by toxic substances, heart failure or injury—in these cases, the membranes of capillaries and alveoli are damaged, but pulmonary artery pressure is not increased.

Unlike the cellular changes accompanying high-altitude pulmonary edema, the mechanisms underlying cerebral edema are elusive. Brain scans of patients have shown both generalized and local swelling. But these findings have been unsuccessful at linking pathology to symptoms. Autopsies have shown generalized edema, scattered small hemorrhages and large clots.

High-altitude residents who acquire chronic mountain sickness have a blunted ventilatory response to lack of oxygen and are thus more hypoxic. In addition, erythropoietin seems to work overtime, creating a proliferation of red blood cells. Together with the exaggerated hypoxia, the greater red blood cell mass increases blood viscosity and can lead to congestive heart failure.

If sea-level residents can be so seriously affected by going to high altitudes, how is it that some mountain climbers can climb and stay as high as...
Although the body can partly compensate for lowered levels of oxygen, many activities remain impaired. Researchers have shown that every 1,000-foot increase in altitude reduces maximum work capacity by 3 percent. Long residence cannot fully restore work capacity toward that at sea level.

D
descendants of people living for many generations at high altitudes show more permanent changes that are probably genetic. Some natives have larger lungs within a barrel chest; others have a substantially increased amount of hemoglobin. More or larger or differently placed mitochondria (the tiny factories that power the cells) are found in populations such as the Quechua of Chile.

Despite centuries of residence, however, no humans have adapted permanently to altitudes higher than 17,000 feet. Sea-level dwellers can live for only a few months at that height before deterioration outruns acclimatization. Over time, people continue to lose weight, their motivation decreases and all bodily functions decline.

Studies of animals offer tantalizing glimpses into the many strategies by which oxygen can be transported and used. Diving seals and whales, for instance, have very large spleens, which serve as a reservoir from which they can draw oxygenated blood. Like humans, their major accommodation is the diversion of blood flow from less to more essential organs, although, unlike us, they shut down certain functions entirely. Other animals, such as yaks and llamas, use different forms of hemoglobin to obtain and hold more oxygen.

For people, acclimatization is best ensured by slow ascent. Indeed, the impatient are likely to become patients. It is a good rule to ascend no more than 2,000 feet a day when above 7,000 feet and to climb at a rate well tolerated by the most vulnerable member of the party. If symptoms become prominent, take a day of rest or even descend a few hundred feet at night. The altitude at which one sleeps is more important than the altitude reached during the day. It is also necessary to drink more water at altitude than at sea level to compensate for the fluid lost through evaporation. Avoiding strenuous exercise for the first day or two is helpful. Taking more salt than usual tends to cause water retention, perhaps enough to trigger altitude sickness.

Those who wish a quick fix may take certain prescription drugs. Acetazolamide inhibits the secretory activity of an enzyme called carbonic anhydrase and thus enables deeper or faster breath-