Breathless and dying on Mount Everest

Abrupt exposure to the enormous 8848 m altitude of Mount Everest would cause loss of consciousness in less than 3 min, but a period of several weeks of progressive acclimatisation allows some humans to survive at such altitude. The functional limits of the body at such extreme hypoxia, especially in relation to lung function, alveolar and blood gases, or oxygen uptake, were established by the Operation Everest I, II, and III-Comex studies, in 1946, 1985, and 1997, respectively, which were done with the use of hypobaric chambers, and by the American Medical Research Expedition to Everest in 1981 and the British Caudwell Xtreme Everest Expedition in 2007, both carried out on Mt Everest itself. During the weather window that occurs on the Himalayas in mid-spring, when Mt Everest is usually climbed with a greater guarantee of success, the average barometric pressure on the summit is about 33·6 kPa and leads to a partial pressure of inspired oxygen (PiO_2) of 5·7 kPa. Just below the summit, an astonishingly low PaO_2 of about 3·3 kPa and an oxygen saturation (SaO_2) of about 55% can be reached, whereas during vigorous exercise when simulating 8848 m altitude in a hypobaric chamber or with low inspired oxygen mixtures, some individuals do not achieve an SaO_2 higher than 40%. However, climbers do not usually exert maximum physical effort during the final ascent to the summit. Those who do not inhale supplemental oxygen maintain very low levels of SaO_2 during their advance, but the levels are not as dangerously low as those observed in altitude-simulated stress tests, avoiding the risk of such extremely low hypoxaemia.

Each year, especially over the past 10 years, Mt Everest has been overcrowded with climbers and up until the summer of 2019, about 10 000 ascents have been made since Edmund Hillary and Tenzing Norgay conquered the summit in 1953. The overall risk of death when climbing Mt Ever has declined over time, from an average of 1·8% i previous century to 0·8% in the current one. This de is most likely to be due to the massive popularisatic commercial expeditions, guided by Sherpas and e mountaineers, which have significantly minimised relative risk despite many climbers being techni underprepared. However, since the first expedi in 1921, more than 300 people have died and this nu continues to rise, with 44% of deaths occurring durin past two decades. Nowadays, more than 95% of atte to reach the summit from the highest camps are m with the aid of inhaling supplemental oxygen; withou the risk of death is more than five times higher, accor to The Himalayan Database.

When approaching the summit, or descending f it, fatalities are most frequently due to exhaustion, or ataxic and cognitive disorders that suggest the presence of cerebral oedema, as Paul Firth and colleagues reported in 2008. Falls, errors, faintness, self-abandonment, and hypothermia can be fatal and can be induced by heavy fatigue or brain oedema. High-altitude pulmonary hypertension, secondary to hypoxia, can induce interstitial or alveolar swelling and alter gas exchange, and subclinical pulmonary oedema is likely to be prevalent at extremely high altitude, worsening hypoxaemia and brain function. In fact, climbers most likely to succeed during these extreme-altitude attempts are those who have a lower pulmonary vasoconstrictor response to hypoxia. Those who are quicker to climb the final ascent of Mt Everest have a better physical and mental state, meaning they have a higher rate of survival; however, the congestion currently registered on the main routes causes hundreds of climbers to get stuck in long lines on the highest ridges, being forced to remain lashed by harsh weather conditions and under the deleterious effects of environmental hypoxia, especially when oxygen tanks are extinguished. Even resting at 8000 m, 2 L/min of supplemental oxygen does not restore the SaO_2 optimally, nor 4 L/min in deteriorated climbers, as recorded during The British th Anniversary Everest Expedition in 1993.

Many climbers have crowned Mt Everest repeatedly—nearly 100 of them more than five times each, with Sherpas being the majority. Himalayan natives have broken many records on this mountain; for example, one individual has made the ascent ten times without supplemental oxygen and is also the only person to date to have climbed it during the winter period without supplemental oxygen. This individual's climb during winter was a special physiological event because the small decline in barometric pressure at an altitude of 8848 m in winter compared with the rest of the

Climbers stuck in a long queue on the southeast upper ridge (8800 m) of Mt Everest in May, 2019

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For more on arterial blood gases and oxygen content in climbers on Mt Everest see N Engl J Med 2009; 360: 140–49

For more on The Himalayan Database see https://www.himalayandatabase.com/

For more on the causes of mortality on Mt Everest see BMJ 2008; 337: a2654

Photograph taken with a polarising filter and reproduced with permission from Josep A Pujante

Empty oxygen bottles scattered along the South Col (7906 m) of Mt Everest, with the troposphere visible after sunrise

For more on elite Sherpas see Med Sci Sports Exer 1997; 29: 937–42

For more on human physiology at extreme altitudes see Science 1984; 223: 784–88

For an overview of high-altitude medicine see Comment Lancet Respir Med 2015; 3: 12–13

For more on the adaptations of Sherpas see Proc Natl Acad Sci USA 2017; 114: 6382–87

year will have substantially decreased an already depleted maximal oxygen uptake (VO_2max). This climb took place on Dec 22, 1987, and we reported in 1997 that the VO_2max of this elite Sherpa at sea level was high (4·37 L/min), which no doubt was a contributing factor to his historic climb. At the summit during winter, VO_2max reduces by almost 80%, despite help with extreme hyperventilation and respiratory alkalosis. With barometric pressure at the summit reaching as low as 32·4 kPa during mid-winter, a feat such as that achieved by this elite Sherpa would be very difficult because at these altitudes VO_2max is highly sensitive to minimal changes in barometric pressure; John West, a physiologist at the University of California, San Diego (CA, USA), also suggested that the reduction in VO_2max during mid-winter is one of the reasons an ascension at this particular time has not yet been achieved without supplementary oxygen. Even so, the highest point on Earth seems still just within the limits of human physiological tolerance.

Since the late 19th century, high-altitude medicine has made valuable contributions to scientific research and provides an opportunity to increase knowledge of respiratory pathophysiology and of critical care patients with hypoxaemia, helping to understand the subtle biological mechanisms involved and shedding light on potential future treatments. Specific genes have been implicated in the regulation of hypoxia, which could be important in finding out the basis of high-altitude adaptations seen in Tibetan ethnic groups. Phenotypic characteristics seen in these groups, such as minimal pulmonary hypertension, optimal ventilation or perfusion match, enhanced tissue oxygen delivery, and metabolic efficiency of cells, can be attributed to their highly differentiated genetic profile and to epigenetic modulation. Nevertheless, despite some individuals having physiological defences against the harmful effects of hypoxia, both Sherpas and foreign climbers have lost their lives near the summit of Mt Everest when they get trapped on the usual routes, which have collapsed due to overcrowding. The risk of death is a high price to pay to climb the highest mountain on Earth.

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We declare no competing interests.