LESSONS FROM HISTORY

The Death Zone: Lessons from History

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This Lessons from History article about the naming of the extreme altitude “Death Zone” explores the historical mountaineering and medical literature relevant to the topic. Swiss alpinist and radiologist Edouard Wyss-Dunant (1897–1983) authored several reports and books about expeditions to arctic regions, deserts, and the Himalaya. Encouraged by the success of a Swiss expedition to the Garhwal Himalaya in 1947, Wyss-Dunant joined his fellow climbers from Geneva on a 1949 expedition to several peaks in the Kanchenjunga region. Wyss-Dunant was then invited to lead the spring 1952 Swiss Everest expedition. Despite this being the first Swiss attempt on Everest and on an untried route, Raymond Lambert and Tenzing Norgay nearly summited Everest from the Nepal side. Wyss-Dunant earned mountaineering immortality by coining the phrase *the Death Zone* during the expedition’s foray into the upper regions of Everest. Wyss-Dunant went on to become a president of the Swiss Alpine Club and the International Climbing and Mountaineering Federation. His writings and that of others provide an evocative supporting narrative to illustrate some of the problems of living (or dying) at extreme altitude.

Keywords: Everest, Mallory, acclimatization, adaptation, deterioration, altitude, Wyss-Dunant

Introduction

The Death Zone is a well-known term in today’s mountaineering, medical, and lay literature. The German term *Todeszone* (Death Zone) was coined by the spring 1952 Swiss Everest Expedition leader and physician Edouard Wyss-Dunant (1897–1983). He described the most perilous aspect of altitude risk in the mountains above a threshold that today is rounded off to coincide with the 14 tallest peaks above 8000 m (26,247 ft).

There have been many extraordinary mountaineering performances with varied outcomes in the Death Zone, where some live and some die. The role of hypoxia is foremost in the Death Zone, but even when supplemental oxygen is provided there is no guarantee of survival. Severe hypoxia is compounded by multiple factors, such as cold and wind exposure, equipment inadequacy or malfunction, workload, cardiorespiratory demands, caloric deficits, dehydration, muscular deconditioning and wasting, and high altitude medical factors including acute mountain sickness (AMS), high altitude pulmonary edema, high altitude

cerebral edema, high altitude deterioration, and more. These issues may occur at altitudes well below the Death Zone, but the incidence accelerates severely as one goes higher.

High altitude deterioration is defined today as “weight loss, poor appetite, slow recovery from fatigue, lethargy, irritability and an increasing lack of will power to start new tasks. There is slowing of mental processes, dulling of affect and impaired cognitive function.”¹ Deterioration begins at about 4570 m (15,000 ft) to 6000 m (19,685 ft), and there is considerable individual variation. This altitude coincides with the definition of extreme altitude as about 5500 m (about 18,000 ft), near the limit of permanent habitation and where atmospheric pressure is roughly half that at sea level. Deterioration advances dramatically more quickly as one goes higher, toward and into the Death Zone; even with adequate warmth, hydration, and nutrition, deterioration inexorably overcomes acclimatization.^{1–5}

This Lessons from History article examines the description and naming of the Death Zone by Wyss-Dunant and includes some of the understanding of physiology as it was known then and as it was evolving. The focus on the Death Zone from the mountaineering literature provides an evocative narrative about Wyss-Dunant’s naming of one of the problems of living (or dying) at extreme altitude.

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Edouard Wyss-Dunant and the Expedition

Edouard Wyss-Dunant (1897–1983) was a radiologist, mountaineer, and leader of the spring 1952 Swiss Everest Expedition. Although this was the first Swiss attempt on Everest and on an untried route, Raymond Lambert and Tenzing Norgay nearly summited Everest from the Nepal side. Wyss-Dunant was a very accomplished alpinist on classical routes in the Bernese Oberland and Mont Blanc. He authored several reports and books about expeditions to Mexico, East Africa, Greenland, Chad, and once previously to the Himalaya before being selected as the 1952 expedition leader. In 1952, Wyss-Dunant himself only reached as far as Camp IV at 6450 m (21,200 ft) in the Western Cwm, but he earned mountaineering immortality by coining the phrase *the Death Zone* in describing the expedition's foray into the upper regions of Everest. The 1953 British Everest expedition leader, John Hunt, praised his predecessor: "This *tour de force* undoubtedly paved the way for our own success in the following year."⁶

During the Swiss Everest attempt in spring 1952, Lambert and Norgay reached about 8600 m (28,200 ft)—just short of the summit—with oxygen sets. They were given credit for breaking the world altitude record for climbers who had ascended and returned safely. The previous record holder, E.F. "Teddy" Norton, reached his eponymous couloir at about 8570 m (28,120 ft) on the north side of Everest in 1924 without supplemental oxygen. Norton sent his mother a letter reassuring her that, inconceivably, he had felt "no more inconvenience from rarity of atmosphere at nearly 27,000 ft [8200 m] that I have done over several 17,000 ft [5200 m] passes."⁷ Norton hypothesized that a higher camp might have helped his summit bid, but he may have underestimated rapid overnight deterioration in the as-yet-unnamed Death Zone. As Beck Weathers, left for dead on Everest in 1996, would dryly point out: "the mountain slowly kills you, whether or not you ever leave your tent."⁸ Norton's 1924 record was tied in 1933 by 3 British climbers who reached the same area, all thwarted by time and terrain and also not using supplemental oxygen.

One source of information about the 1952 Swiss expedition to Everest is *Forerunners to Everest* by René Dittert, Raymond Lambert, and team physician Gabriel Chevalley.⁹ There is a short account by Wyss-Dunant in *The Geographical Journal*.¹⁰ Even more important is a longer expedition report from the Swiss Foundation for Alpine Research with Wyss-Dunant's chapter *Die Akklimatisation* (Acclimatization) in *Berge der Welt* (Mountains of the World) and the translation published in *The Mountain World 1953*.^{11,12} In the preface to the English version was a caution by the editor: "We realise that our objective is beset with snags; and we trust that our translators will

increasingly succeed in communicating to readers in other languages the essential meaning of the original."¹³ This disclaimer was well placed.

The Zones of Edouard Wyss-Dunant

Wyss-Dunant described areas of concern at certain altitudes that will be divided into 5 sections here. These sections are (1) the march from Kathmandu, (2) "Acclimatisation to high altitude," (3) "Adaptation and deterioration," (4) the "lethal zone," and (5) the "ultimate zone."¹² Each will be reviewed.

In the first section, Wyss-Dunant remarked on the 18-d approach up and down the Himalayan-grade foothills from Kathmandu to base camp, but he mainly emphasized physical toning and dealing with gastrointestinal issues. Making a distinction, he wrote: "Acclimatisation in the Himalaya has nothing to do with training on the march on with altitudes up to about 15,000 ft [4600 m], a training which every Himalayist should have acquired in advance."¹² The training advice was wise, but acclimatization begins long before that height. Physiologic changes begin before reaching 2500 m (about 8000 ft), and even the pathologic conditions AMS, high altitude pulmonary edema, and high altitude cerebral edema cannot be excluded at that altitude.¹⁴ The "march on" to the 1952 Swiss Everest base camp was initially to the Khumbu glacier at 5050 m (16,600 ft) at an area just below the current trekking lodges at Gorak Shep. Wyss-Dunant seemed to discount the benefit of the walk-in for acclimatization, but later in the chapter he did value it at a much higher elevation: "In the Himalaya, the long duration of the approach march resolves the problem from this point of view."¹²

Moving higher, to the second section, Wyss-Dunant declared that "Acclimatisation to high altitude begins as from the base camp."¹² He specified the height and characteristics, writing that "The headaches which begin between 16,500 and 19,500 ft [about 5000 and 5900 m] are probably due to the differences in barometric pressure; they disappear quite quickly under the influence of acclimatisation."¹² The headaches of AMS actually did occur before the height of base camp but were mostly avoided by acclimatizing on the long journey from Kathmandu. As an aside, expedition leader Wyss-Dunant was a radiologist, but Chevalley was the team medical doctor and needed to dispense acetylsalicylic acid for headaches before reaching base camp.⁹ Stronger headaches above base camp were likely provoked by the greater altitude and were relieved by acclimatizing to that new height.

Wyss-Dunant stated that "The irregular Cheyne-Stokes respiration at night, a phenomenon not yet completely explained, likewise disappears with acclimatisation."¹² Chevalley had noted these respirations beginning much

lower, at Namche Bazaar at about 3400 m (11,150 ft).⁹ Cheyne-Stokes breathing has a different cause and respiratory pattern than the irregular respirations of sojourners to high altitude, which is called *periodic breathing of altitude*. Periodic breathing does not completely disappear in the time at altitude. It is now understood to continue there, but overall sleep architecture and quality does improve with acclimatization.^{1,15} This change might have been what both Wyss-Dunant and Chevalley witnessed on this expedition. Periodic breathing is more related to hypoxia than to AMS. Abnormal sleep is now recognized as expected at high altitude and not a symptom of AMS. In 2018, this led to a revision of the Lake Louise AMS Score.¹⁶

In this second section, Wyss-Dunant overestimated the persistence of acclimatization in one passage: “Acclimatisation to high altitudes, once acquired, lasts for many years.”¹² The direct benefits of acclimatization do not last for years for expedition members. One rule of thumb is that, after descent, it takes about as much time to lose acclimatization as it did to gain it.^{17,18} Some individuals may have more “carry-over” than others, but assertions that acclimatization endures for years or a lifetime are anecdotal and it is difficult to design and implement a study to test this. Returning climbers may acquire the ability to engage in faster or safer subsequent visits to altitude.¹⁸ Their familiarity with the demands of altitude, maintaining hydration, proper pacing, and other experience is beneficial.

Still, in his discussion about being just above base camp, Wyss-Dunant perceived that “There is not yet, in the zone of acclimatisation, any irrecoverable loss of energy, provided that the time necessary for acclimatisation has been sufficient.”¹² In other words, a properly acclimatized individual could climb, recuperate, and climb some more. This is true in the short run, but the range Wyss-Dunant gives for the zone of acclimatization is also where high altitude deterioration slowly begins, eating away at the gains of acclimatization. More will be said about deterioration in the next section.

The third section by Wyss-Dunant, entitled “Adaptation and deterioration,” discusses the time between 5950 m (19,500 ft) and 7800 to 7900 m (25,500–26,000 ft).¹² Adaptation to altitude and deterioration from altitude must be examined because both are fundamental to the Death Zone story. The word *adaptation* is problematic and is discussed first.

The German verb *anpassen* was translated as “adapt” or “accustom” in the English version. The choice of nouns was complex. Some of the nouns could have been translated differently, so the examples shown here are verbatim from the British English version, along with current suggested corrections: *Anpassung* (used for both “acclimatisation” and “adaptation”); *Anpassungsfähigkeit* (“suppleness

in acclimatisation,” perhaps better translated as capacity for acclimatization); the hybrid words *Adaptationfähigkeit* (“capacity for adaptation”), *Adaptationsleistungen* (“adaptation without injury,” perhaps better translated as power or performance in adaptation) and *Höhenadaptation* (“adaptation to altitude”); and the borrowed word *Adaptation*.^{11,12}

To clarify, the physical responses that Wyss-Dunant reported on the mountain were temporary short-term physiologic or pathophysiologic responses as the body attempted to adapt or adjust or acclimatize to altitude during the 2 months the expedition was there. The word *adaptation* has variable usage. The process of being adapted is adaptation, but at height the word adaptation can mean either short-term responses to altitude (as Wyss-Dunant used it) or long-term changes in the fitness of populations to live at high altitude by factors including genetic adaptation. The latter means a transformational, evolutionary, and mainly beneficial process taking many generations, as in high altitude populations, but not in climbers during the limited length of an expedition. Although forms of adaptation were known by, for example, naturalists Charles Darwin and Alfred Wallace in the 19th century and environmental physiologist D.B. Dill in the 20th century, the words *adapt*, *adaptation*, *acclimatize*, and *acclimatization* were initially used interchangeably and confusingly in the developing field of mountain medicine. Today, long-term biological adaptation in native high altitude populations is better understood through a growing knowledge of topics such as hypoxia-inducible factors and relationships between genetic and physiologic variants.^{19,20}

To be fair, the reading of Wyss-Dunant’s work must be done considering the perspective of the translation and the mountaineering and physiology knowns and unknowns of that time. Therefore, this modern-day evaluation should not be seen as overcritical. With clinical descriptions of physiologic responses and pathophysiologic changes at various altitudes, Wyss-Dunant’s *Todeszone* was well named and will be explained later in the fourth section.

Deterioration, the next topic, was clinically described by explorers and mountaineers in years past, when the complaint was known as the older term *mountain lassitude*. Deterioration is distinct from simple lassitude or lassitude in mountain sickness (AMS).^{5,21-23} Rather than mountain lassitude, the phrase *high altitude deterioration* became more commonplace. It was attributed to surgeon-mountaineer T. Howard Somervell on the British Everest expeditions of 1922 and 1924.^{2,3,5,18} On the 1922 expedition, George Mallory emphasized with italics when he wrote that there was only 1 solution for deterioration: “At a high altitude even the strongest might suffer this loss of muscular power; and he will not recover up there.”²⁴ In 1932, British climber-writer Frank Smythe on Kamet would advise with

wit: “if he would enjoy himself, the Himalayan mountaineer should limit himself to peaks less than 23,000 feet [7000 m].”²⁵ Wyss-Dunant implied much the same: “one can no longer acclimatise oneself to 23,000 ft [7000 m].”¹²

In 1935, a team including American physiologists Ancel Keys and D.B. Dill, observed the workforce at the Aconquilcha sulfur mines in Chile at about 5950 m (19,500 ft). Miners and families had abandoned a nearby camp, preferring to descend daily to the town of Aconquilcha at about 5300 m (17,500 ft). With limitations from deterioration and other factors, this location was thought to be at the highest permanently habitable altitude at that time.^{26,27} Others made observations about altitude effects over the years, but it was not until 1960 to 1961 that a comprehensive study on altitude physiology was performed by expedition members spending months at high and extreme altitudes on the “Silver Hut” Himalayan Scientific and Mountaineering Expedition led by British physiologist Griffith Pugh.⁴ Regarding deterioration, he concluded that “19,000 ft [5800 m] was too high for complete adjustment [to allow permanent habitation] and that 17,000 ft [5300 m], or in some cases 15,000 ft [4600 m], would be nearer the limit.”⁴ Physicians Pugh and Michael Ward reflected on the early Everest era: “By 1933 the view was generally...recognised that little if any acclimatisation was possible above 23,000 ft [about 7000 m], and deterioration was more rapid and severe the greater the altitude reached.”²⁸

Wyss-Dunant used the term deterioration correctly. He had recognized that “The individual lives on his reserves, his stay above 23,000 ft [7000 m] will be limited.”¹² At this height, and especially higher, the length of time spent is crucial; as in the proverbial math formula of the bathtub simultaneously filling and draining, beneficial acclimatization loses the battle against the inexorable advance of deterioration. Swiss climbing leader Dittert made nearly the same grave pronouncement about this height, “where deterioration begins remorselessly to destroy the benefits of acclimatisation.”⁹ Wyss-Dunant italicized this accurate warning about the length of stay: “*For there was nothing to be gained by prolonging so high a sojourn.*”¹² The end result of all these experiences is that most modern Everest climbers begin using supplemental oxygen at about this height on the Lhotse Face at 7200 m (23,600 ft).²⁹

Wyss-Dunant’s discussion of deterioration concluded with his naming of the *Todeszone* at above about 7800 to 7900 m (25,500–26,000 ft). The Swiss climbers were at the South Col, the saddle between Lhotse and Everest. It was a fitting location to designate a Death Zone. The South Col is a milestone (or tombstone) on the way to or from the summit of Everest. A year after the Swiss expedition, British climber Wilfrid Noyce would describe the risk of hypoxia there, announcing that “The top layers of my brain were probably dormant up there” and, even more

dangerously, that “I thought I was as alert as at sea level.”³⁰ Such loss of executive function can lead to bad mountaineering judgment and disaster. The risk of hypoxia and deterioration at the South Col also exists at similar extreme heights on other mountains in the Himalaya and Karakoram and is just as life-threatening.

Wyss-Dunant coined his famous term over several sentences. In German, nouns are capitalized. *Todeszone* is *death zone* in English, but in customary English usage today it is often capitalized for emphasis. To be picayune, the English translation of Wyss-Dunant, as will be seen, only had “lethal zone” and “mortal zone” but not “death zone” or “Death Zone.” He gave this advice about the *Todeszone*: “Only one possibility exists there, since recuperation is non-existent, and that is to live on one’s reserves for the three or four days necessary for the attack on the peak...That is the necessary condition for facing the lethal zone and its mortal dangers.”¹² With recuperation not possible, Wyss-Dunant concluded: “I have spoken of the ‘lethal zone’: it is fitting to give some explanation of this term. *Survival* is the only term suitable for describing the behaviour of a man in that mortal zone which begins at about 25,500 ft [7800 m]. Life there is impossible and it requires the whole of a man’s will to maintain himself there for a few days. Life hangs by a thread.”¹² It is remarkable that *Todeszone*, buried in the German literature and translated into English, would be raised up to become one of the most recognized mountaineering terms of all times.

Mountaineers on the 1922 British Everest Expedition were the first to enter the yet-to-be named Death Zone. Mallory was in a roped party of 3 with Norton and Somervell, reaching about 8250 m (27,000 ft).³¹ Sadly, 2 years later, Mallory was in a party of 2 with Sandy Irvine when they became the first to die in the Death Zone.³²

On the 1953 Nanga Parbat expedition, the controversial physician-leader Karl Herrligkoffer was succinct about what became known as “The Killer Mountain.” He wrote: “In its last phases the ascent of a peak above 26,000 feet [7900 m] approximates to a race with death.”³³ This race has a hard finish line. Survival time in the Death Zone for those lucky enough to stay alive at all may only be hours or days. The record length of endurance in the Death Zone may have been during the 1986 multifatality disaster high on K2. Austrians Kurt Diemberger and Willi Bauer spent 5 d camped at 8500 m (about 28,000 ft), with Bauer setting the >8000-m survival record of 10 d.³⁴

Wyss-Dunant’s fifth and ultimate zone was where he thought humans would require supplemental oxygen to climb to the top of Everest. He first briefly reviewed the lore about the altitude record that was not broken until Lambert and Tenzing “succeeded in penetrating this zone to something above 28,200 ft [8600 m] after passing a very difficult night in their tent at about 27,560 ft [8400 m].”¹²

He summed up the event: “Their stay in the lethal zone, and [briefly] afterwards in the ultimate zone... had lasted three days.”¹²

Wyss-Dunant was one of many who believed that supplemental oxygen was required to successfully reach the 8850 m (29,035 ft) summit of Everest. Smythe in 1933 had remarked: “Those who tread its last 1,000 feet [300 m] tread the physical limits of the world.”³⁵ Wyss-Dunant declared the need for oxygen: “8500 metres [about 28,000 ft] does seem to be the physiological limit for the human organism without the aid of oxygen apparatus,” and he noted that “this zone is a limit, and human strength will only be able to cross it on the day when technical perfection will make it possible to ameliorate the physiological conditions artificially.”^{10,12}

It was not just oxygen that the Swiss needed in 1952. They had ample advice and experience, but, for example, words like *thirst* occur throughout the Swiss accounts. In 1952 at Camp VI on the South Col they used solid fuel stoves with known limited ability to melt ice for drinking water. Lambert and Tenzing had only a candle for this purpose even higher at Camp VII on their summit bid.³⁶ The British, on the other hand, had Pugh’s groundbreaking physiological and practical work to improve stoves, hydration, hygiene, clothing, acclimatization schedule, and more to help convert yet another possible failed British attempt into the success of the 1953 expedition.³⁷

Of all the factors affecting the oxygen cascade down to the mitochondria, barometric pressure is first and foremost for mountaineers. Carrying sufficient oxygen, delivering it properly, and understanding the physiology were all issues. Pugh’s oxygen studies on the 1952 British Cho Oyu expedition and working with the British Medical Research Council High Altitude Committee resulted in marked improvements, such as more effective masks for climbers with high respiratory volumes, higher oxygen flow rates, and far greater supply of oxygen on Everest in 1953 than the Swiss took in 1952.^{37,38}

There were two main types of oxygen systems. Closed-circuit sets that chemically produced oxygen and absorbed carbon dioxide had a history of difficulties. The latest version for the British in 1953 was modified by the father-son team of Robert and Tom Bourdillon and was used for the first summit attempt. Tom Bourdillon and Charles Evans set a new altitude record by reaching the South Summit of Everest. Mechanical problems, including frozen valves in 1 unit, prevented them from safely going higher. The second and successful summit attempt by Norgay and Edmund Hillary used the simpler open-circuit method with bottled oxygen that mixed with ambient air. Breath with carbon dioxide was simply exhaled rather than being absorbed as in the closed-loop system. The open-circuit system was useful both during climbing and

at rest. The British also had a separate open-circuit set for sleeping.³⁹ The Swiss in spring 1952 used a closed-circuit system based on American mining rescue equipment that they had very recently modified with limited testing. The Swiss tube and rigid mouthpiece system restricted oxygen flow, reduced climbers’ mobility, and was unsuitable for climbing when ventilatory rates were high. Adequate amounts of oxygen could be obtained only while at rest.³⁷⁻⁴²

Both Wyss-Dunant and Chevalley explained it similarly: “too great resistance to the breathing action... [and] since the tissues are unable to accumulate a reserve of oxygen, the benefit of the inhalations in combatting [sic] deterioration during rest is limited in duration, that is to say, very small if those inhalations are only very intermittent.”⁴³ They were right. According to Australian-American physiologist John West, one reason for the spring 1952 Swiss expedition’s inability to summit Everest was their oxygen equipment.⁴⁰ Chevalley returned in the fall to lead another Swiss attempt. He emulated the British by bringing open-circuit sets and much more oxygen, but the late season, other factors, and especially an inadequate understanding of the physiology of life at extreme altitude took their toll.^{9,42}

To speculate about exceeding Wyss-Dunant’s ultimate limit, it must be recalled that the summit of Everest is near the boundary of human tolerance to hypoxia.⁴⁴ However, with post-1952 advances in weather reporting, gear, mountaineering expertise, and especially in rapid alpine ascents rather than siege tactics, the duration of exposure to deterioration was reduced. Scottish chemistry lecturer and Himalayan veteran Alexander Kellas suggested the possibility of summiting Everest without supplemental oxygen back in 1920.²³ Although Norgay and Hillary would accomplish the first ascent of Everest in 1953 using supplemental oxygen, it was not until 1978 that Italian Reinhold Messner and Austrian Peter Habeler dispelled the years of negative prognostications about ascending Everest “by fair means.” A select few would go on to set even more records without supplemental oxygen on Everest and all of the 8000-m peaks.

The glass ceiling of Wyss-Dunant’s ultimate zone has been shattered, but barely. The problem is that while breathing air alone, the maximal consumption of oxygen at the summit of Everest is only about 1 L·min⁻¹. This is enough for basal metabolism and leaves only a little for the energy requirements of climbing, thinking, warmth, and, even more importantly, descending to safety.^{1,44} Kellas foretold in 1920 that the climbing rate near the summit of Everest would be about 90 to 110 m·h⁻¹ (300–350 ft·h⁻¹) without supplemental oxygen.^{23,45} This was in Wyss-Dunant’s ultimate zone. The “true” ultimate zone is even higher than Wyss-Dunant thought, but from a mountaineering

perspective it is unknowable and unattainable; one cannot climb higher than Everest.

Conclusions

This article reviewed an important concept in mountaineering that was first named by Edouard Wyss-Dunant on the 1952 Swiss Everest expedition. His term, the Death Zone, lives on.

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References

- West JB, Schoene RB, Luks AM, Milledge JS. *High Altitude Medicine and Physiology*. 5th ed. Boca Raton, FL: CRC Press Taylor & Francis; 2013:53–64, 216–29;280–299.
- Ward M. High altitude deterioration. *Proc R Soc Lond B Biol Sci*. 1954;143(910):40–2.
- Ward MP, Milledge JS, West JB. *High Altitude Medicine and Physiology*. 1st ed. London, UK: Chapman & Hall Medical; 1989:70.
- Pugh LG. Physiological and medical aspects of the Himalayan scientific and mountaineering expedition, 1960–1961. *Br Med J*. 1962;2(5305):621–7.
- Lankford HV. High altitude deterioration: a historical essay. *Wilderness Environ Med*. 2019;30(3):328–33.
- Hunt J. In memoriam. Dr. Edouard Wyss-Dunant. 1897–1983. (Hon Member 1949). *Alpine J*. 1984;89:262.
- Norton EF, Norton C, eds. *Everest Revealed*. Stroud, UK: History Press; 2014:64.
- Weathers B. *Left for Dead. My Journey Home from Everest*. New York: Villard; 2000:29.
- Dittert R, Chevalley G, Lambert R. *Forerunners to Everest*. New York: Harper & Bros; 1954:49;63; 96;113;188;253–255.
- Wyss-Dunant E. The first Swiss expedition to Mount Everest 1952. *Geogr J*. 1953;119(3):266–77.
- Wyss-Dunant E. Die Akklimatisation. In: Kurz M, ed. *Berge der Welt. Das Buch der Forscher und Bergsteiger*. Zurich: Gutenberg; 1953:109–16.
- Wyss-Dunant E. Acclimatisation. In: Kurz M, ed. *The Mountain World 1953*. London: Allen & Unwin; 1953:110–7.
- Kurz M, ed. *The Mountain World 1953*. London: Allen & Unwin; 1953:7.
- Luks AM, Auerbach PS, Freer L, Grissom CK, Keyes LE, McIntosh SE, et al. Wilderness Medical Society clinical practice guidelines for the prevention and treatment of acute altitude illness: 2019 update. *Wilderness Environ Med*. 2019;30(4S):S3–18.
- Nussbaumer-Ochsner Y, Ursprung J, Siebenmann C, Maggiorini M, Bloch KE. Effect of short-term acclimatization to high altitude on sleep and nocturnal breathing. *Sleep*. 2012;35(3):419–23.
- Roach RC, Hackett PH, Oelz O, Bartsch P, Luks AM, MacInnis MJ, et al. The 2018 Lake Louise acute mountain sickness score. *High Alt Med Biol*. 2018;19(1):4–6.
- Hultgren HN. *High Altitude Medicine*. Stanford: Hultgren Publications; 1997:176.
- Ward M. Man and the mountain environment. *Alpine J*. 1969;74:133–47.
- Semenza GL. Hypoxia-inducible factors in physiology and medicine. *Cell*. 2012;148(3):399–408.
- Simonson TS. Altitude adaptation: a glimpse through various lenses. *High Alt Med Biol*. 2015;16(2):125–37.
- Whympers E. Upon some results of the journey. *Travels Amongst the Great Andes of the Equator*. London: J Murray; 1892:370–1.
- Longstaff TG. *Mountain Sickness and its Probable Causes*. London: Spottiswoodie; 1906:17;38;49.
- Kellas AM. A consideration of the possibility of ascending Mount Everest. *High Alt Med Biol*. 2001;2(3):431–62.
- Mallory G. The second Mount Everest expedition. *Alpine J*. 1922;34:425ff.
- Smythe FS. *Kamet Conquered*. London: Victor Gallancz; 1932:488.
- Dill DB. *Life, Heat, and Altitude. Physiological Effects of Hot Climates and Great Heights*. Cambridge, MA: Harvard University Press; 1938.
- West JB. Highest permanent human habitation. *High Alt Med Biol*. 2004;3(4):401–7.
- Pugh LG, Ward MP. Some effects of high altitude on man. *Alpine J*. 1957;61:507–20.
- Arnette A. Mt. Everest Southeast Ridge. Available at: <https://www.alanarnette.com/everest/everestsouthroutes.php>. Accessed May 11, 2020.
- Noyce W. *South Col*. London: Heinemann; 1954:237.
- Bruce CG. *The Assault on Mount Everest 1922*. London: Arnold; 1923.
- Odell NE. Mallory and Irvine's attempt. In: Norton EF, ed. *The Fight for Everest 1924*. London: Longmans Green; 1925:120–43.
- Herrligkoff K. *Nanga Parbat*. New York: Knopf; 1954:258.
- Curran J. *K2 Triumph and Tragedy*. Boston: Houghton Mifflin; 1987:161.
- Smythe FS. The Second Assault. In: Ruttledge H, ed. *Everest 1933*. London: Hodder & Stoughton; 1936:207.
- Lambert R. The attack upon the summit. In: Kurz M, ed. *The Mountain World 1953*. London: Allen & Unwin; 1953:93.
- Tuckey H. *Everest the First Ascent. The Untold Story of Griffith Pugh, the Man Who Made It Possible*. London: Rider; 2013.
- Pugh LG. Physiology & Medicine. In: Hunt J. *The Conquest of Everest*. New York: Dutton; 270–7.
- Bourdillon TD. Oxygen equipment. In: Hunt J. *The Conquest of Everest*. New York: Dutton; 257–262.
- West JB. Failure on Everest: the oxygen equipment of the spring 1952 Swiss expedition. *High Alt Med Biol*. 2003;4(1):39–43.

41. Windsor JS, Rodway GW, Dick J. The use of closed-circuit oxygen in the Himalayas. *High Alt Med Biol.* 2005;6(3):263–9.
42. Sale R, Rodway G. *Everest & Conquest in the Himalaya. Science and Courage on the Worlds' Highest Mountain.* Barnsley, UK: Pen & Sword Books; 2011:60–79.
43. Chevalley G. Man at Great Heights. In: Kurz M, ed. *The Mountain World 1953.* London: Allen & Unwin; 1953:100.
44. West JB. American medical research expedition to Everest. *High Alt Med Biol.* 2010;11(2):103–10.
45. West JB, Alexander M. Kellas and the physiological challenge of Mt. Everest. *J Appl Physiol.* 1987;63(1):3–11.