Chapter 15

Mountaineering in thin air

Patterns of death and of weather at high altitude

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Abstract: An 8000-m peak bring challenges of extremes of hypoxia and weather as well as the normal hazards of climbing itself. These challenges have taken a severe toll: 604 mountaineers have died on those great peaks since 1950. Little is known about whether mountain height, use of supplemental oxygen, or team size might influence rates of death or of success. However, such information may provide insights not only to our understanding of the limits of human performance, but also to mountaineers in making decisions on these peaks. We present several examples from a research program that is attempting to analyze factors that potentially influence success or death rates on the 8K peaks. (1) Apparent risk of death in the notorious Khumbu Icefall on Mt. Everest has declined dramatically in recent years. This decline could reflect improved route finding and technique, but might also reflect climate warming, which has caused the Khumbu glacier to shrink and slow in recent decades. (2) Risk of death during descent from an 8000-m peak increases with the height of the peak. (3) Risk of death during descent from the summit of Everest or of K2 is elevated for climbers not using supplemental oxygen. (4) We outline some new studies that are exploring how convective heat loss, which influences wind chill, changes with altitude as well as the incidence of storms: both factors will impact the probability success and death of Himalayan mountaineers.

Key words: Everest, K2, supplemental oxygen, wind chill, convection

INTRODUCTION

Each year thousands of mountaineers venture to the 8000-m peaks of the Himalaya in pursuit of adventure. Each year, some reach a summit; and each

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year, a few die. Indeed, a mountaineer's odds of success and of death are demonstrably worse than on lesser peaks (8).

What factors influence the probability of success – and that of death – on the 8K peaks? Remarkably little is known about this issue, despite the extraordinary attention that Himalayan mountaineering inevitably attracts. In fact, prior compilations of quantitative patterns of success and death on the 8K peaks (or any peaks for that matter) are scant. Pollard and Clark (17) were the first to test a specific hypothesis (the probability of death from medical causes would increase with altitude). Recently, we tested the hypothesis that death rate during descent from the summit of Everest or K2 is reduced for climbers using supplemental oxygen than for those using ambient air (4,7). These analyses show that quantitative patterns can be detected from mountaineering data (4)

Here we describe several examples of our research program, which is attempting to analyze factors that might influence the probabilities of success and of death on the 8K peaks. For example, we are exploring whether behavioral choices that a mountaineer makes (e.g., to use supplemental oxygen, to climb alpine style, to climb in winter) influence success and death rates. Similarly we attempt to analyze certain environmental factors (summit height, route steepness, weather) that might also influence those rates. However, we are not currently examining the possible impact of physiological or genetical differences among climbers (11,14).

The general approach

Analyses of Himalayan mountaineering are inherently based on historical data. Experimental approaches, in which one experimentally manipulates one or more variables of interest, are simply not an option (8). Instead, we use a hypothesis-based approach that is rooted in deductive logic (27). Thus we start from an established base of physiological information and derive specific, physiologically plausible predictions. For example, knowing that supplemental oxygen enhances physiological performance at altitude (15), we predicted that death rate during descent from the summit of a high peak is reduced for climbers that use supplemental oxygen (7). We then compile relevant historical data and conduct statistical analyses.

Significant statistical support -- even for an a priori hypothesis -- does not, of course, necessarily imply cause and effect (27): confounding factors can easily distort analyses. This is, of course, a classical problem in epidemiology (24). Accordingly, we attempt to evaluate the robustness of any observed support by considering alternative factors that might confound observed statistical associations. However, as is described below, such evaluations are unfortunately not always feasible or at least easy. Therefore, we try to be candid as to known uncertainties and alternatives. Readers can then evaluate for themselves the plausibility of cause and effect.

Are statistical approaches useful?

Before reviewing specific analyses, we want to address a fundamental question, namely, do statistics even have place in mountaineering? Some people may feel that statistical analyses are an inappropriate academic intrusion into what should be a wilderness experience. Others may feel that any conclusions drawn from such an analysis are inherently suspect, given that all such analyses are historical and thus non-experimental. We recognize these concerns, but we feel that patterns derived from statistical analyses are still informative, though not definitive.

To illustrate the utility of a quantitative approach, we briefly describe two examples from mountaineering on Mt. Everest. One shows that a statistical approach can sometimes contradict conventional wisdom that is popular but nonetheless patently false. A second presents an example of a generalization that might once have been correct during the formative years of climbing on Everest, but that is no longer correct.

A widespread assertion, seen commonly both in newspapers and even in JAMA (5), is that one in five (or even one in four!) climbers die on Mt. Everest. In fact, the death rate for mountaineers (exclusive of porters, Sherpas, and commercial guides) is actually about one in 48 (R. Salisbury and E. Hawley, personal communication), an order of magnitude lower! In this example a quantitative approach corrects an obvious error that might well have caused considerable anxiety to family and friends of mountaineers. [How could such an obvious error have started? Most likely, the one in five "death rate" probably derives (20) from computing the ratio of the number of climbers who have died *anywhere* on Everest relative to the *number of climbers who have summited*. This ratio may be of interest, but it is certainly not a death rate, which is number of climbers who have died divided by *the number who were at risk on the mountain*.]

A second example concerns the infamous Icefall of the Khumbu Glacier. The Icefall has long been regarded as the most terrifying and dangerous part of the route: even a key history of Everest stated that more deaths have occurred in the Icefall than elsewhere on the mountain (26).

Is the Icefall really the most deadly part of the normal route on Everest? In the early decades, most deaths were indeed in the Icefall; but only one death has occurred in the Icefall since 1987 (R. Huey, A. Salkeld, J. Edwards, E. Hawley, and R. Salisbury, in preparation)! Because *many* people now pass through the Icefall each year, the current death rate – even on a per climber basis – must be near zero. In contrast, most of the recent deaths have occurred on the SE Ridge, even though traffic on that ridge is miniscule relative to that through the Icefall. Thus, although the Icefall is still undoubtedly dangerous, it is far from the deadliest section on the mountain.

In this example, a quantitative analysis shows that a widespread view, which might once have been valid, is no longer so. Knowing that the SE Ridge, not the Icefall, is the deadliest section should be very relevant to mountaineers. In effect, the Icefall's reputation (26) is now a red herring, and so may put lives at risk.

Why has risk dropped in the Icefall? We can offer two possibilities. First, better route finding, equipment, and technique almost certainly play a role. Indeed, the Icefall route is now maintained by "Icefall Doctors," who charge climbers for access (9)! Second, climate warming may be indirectly responsible. Himalayan temperatures has been warming for several decades (Figure 1), and the Khumbu glacier in particular has been shrinking and slowing (13,19). Perhaps the slowing of the glacier stabilizes the route and reduced risk of death from serac fall or of glacial avalanches.

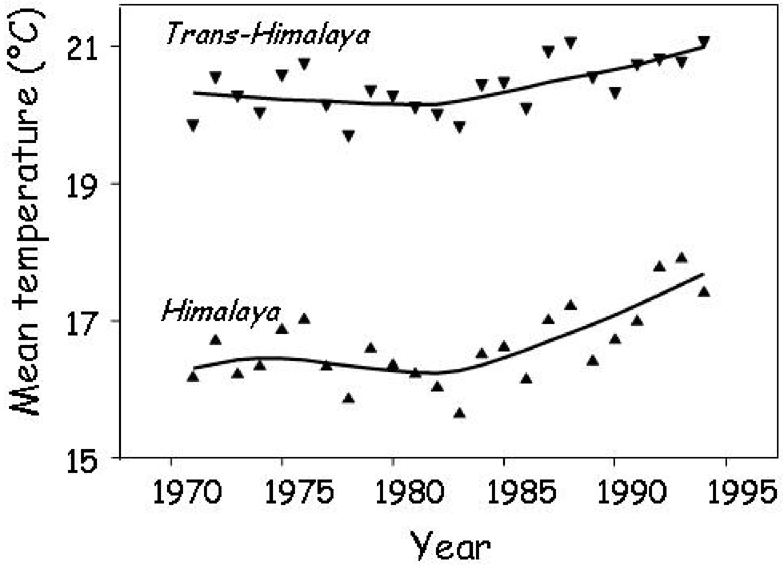

Figure 1. Climate warming in two mountain regions of Nepal. Data courtesy of A. B. Shrestha (21)

This analysis shows that historical statistical analyses can detect pattern. However, it also highlights a basic limitation, namely, the difficulty of evaluating competing processes that potentially underlie that pattern (27). Of course, to a mountaineer attempting Everest, pattern counts: process may be academic.

Mountain height and death rate

Mountaineers are preferentially attracted to the highest summits of the Himalaya, especially to Everest (6). However, because the severity of hypoxic stress (15,28) and of storms (16) increases with the altitude of those summits, risk of death might increase with summit height. Overall risk of death is known so far for only a few 8K peaks (8), but death rates during descent from the summit are now known for all of 14 of the 8K peaks. Consequently, we can test the physiologically based prediction that death rates during descent from the summit increase with the height of a peak.

We analyzed data for all mountaineers who reached the summit of an 8,000-m peak through 2000. On the two highest peaks (Everest and K2), mountaineers commonly use supplemental oxygen (7), which reduces hypoxic stress (15), effectively lowers the "physiological" height of a peak (10) and which is associated with reduced death rates (7). To help standardize comparisons, we therefore excluded data on climbers on these two peaks who used supplemental oxygen. Some climbers who used supplemental oxygen on the other peaks will be included, but hopefully they should be relatively few. We then regressed descent death rate (angular transformed) on altitude (one-tailed test).

Through 2000, 3803 ascents were made on the 8,000-m peaks (range 98 to 1211 ascents per peak, *excluding* O2-ascents on Everest and K2). Death rate during these descents averaged 3.8% (~ 1 in 26) and ranged from 0.4% on Cho Oyu to 17.3% on K2 (Figure 2). Death rate increased significantly with altitude (Figure 2, $P = 0.009$, $R^2 = 0.39$), even though the maximum difference in altitudes is ~ 800m (Gasherbrum II vs. Everest).

We checked several potentially confounding factors that might cause a spurious correlation between summit altitude and death rate. Reassuringly, altitude remains significant even if data for climbers using supplemental oxygen on Everest and K2 are included ($P = 0.044$) or even if nine K2 climbers that were killed in fierce storms in 1986 and 1995 are excluded ($P = 0.018$). [Thus, the pattern is not an artifact of two severe storms that trapped summit climbers on K2.] Also, descent death rate might increase with summit altitude not because of altitude per se, but perhaps high peaks are farther from base camp, thus prolonging a descending climbers exposure. However, elevational difference between base camp and summit was not significant ($P = 0.18$).

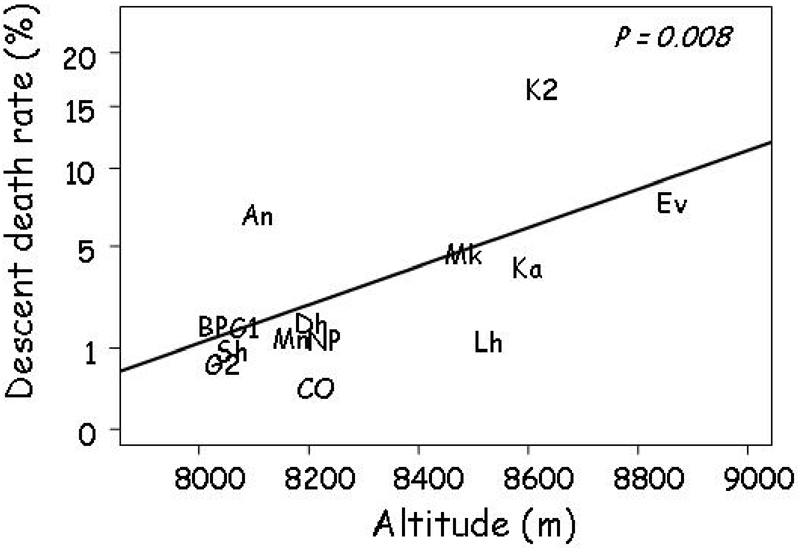

Figure 2. Death rates during descent (through 2000) in relation to the height of each 8000m peaks (symbols are abbreviations for peak names)

Although we can exclude some potentially confounding factors, we can't exclude some factors (e.g., steepness, rock quality, avalanche risk, climber skill and behavior) that might co-vary with altitude: consequently, additional studies will be required to elucidate whether altitude per se is actually the dominant causal factor. Unfortunately, the data necessary to evaluate such alternative factors will be difficulty to compile.

Altitude can't be the only factor influencing descent death rates. Annapurna is relatively small but nonetheless has a high descent death rate (probably because of high avalanche risk), whereas Lhotse is relatively big but has a low descent death rate (Figure 2). Nevertheless, the overall pattern is suggestive and consistent with physiological considerations: higher Himalayan peaks are deadlier, at least during descent from the summit.

Supplemental oxygen and death rate

In 1878 Paul Bert proposed using supplemental oxygen to reduce the physiological deterioration caused by hypoxia at altitude (1). Bert's suggestion was first implemented in the Himalaya early last century, and is still heavily used there on the highest peaks until this day. The use of supplemental oxygen has, however, always been controversial. For example, some climbers feel that supplemental oxygen use is unsporting (10,25). Even so, supplemental oxygen does enhance performance at high altitude (15), and thus it might possible enhance survival as well.

We recently analyzed (7) a possible association between use of supplemental oxygen and death rates during descent from the summits of Everest and K2, the two highest peaks in the world. Our main data set included the years 1978, when the first ascents without supplemental oxygen were made on these peaks, through 1999. We found that death rates during descent were elevated for climbers who had not used supplemental oxygen, and the pattern was especially conspicuous on K2. In 2000 climbers were very successful on both mountains, and only one death occurred during descent (on Everest). To determine whether the pattern still held, we therefore reanalyzed the data, adding the data from 2000 (Figure 3). We used an exact logistic regression, with individual survival as the dependent variable, with supplemental oxygen use as a factor, and mountain as a stratum (7).

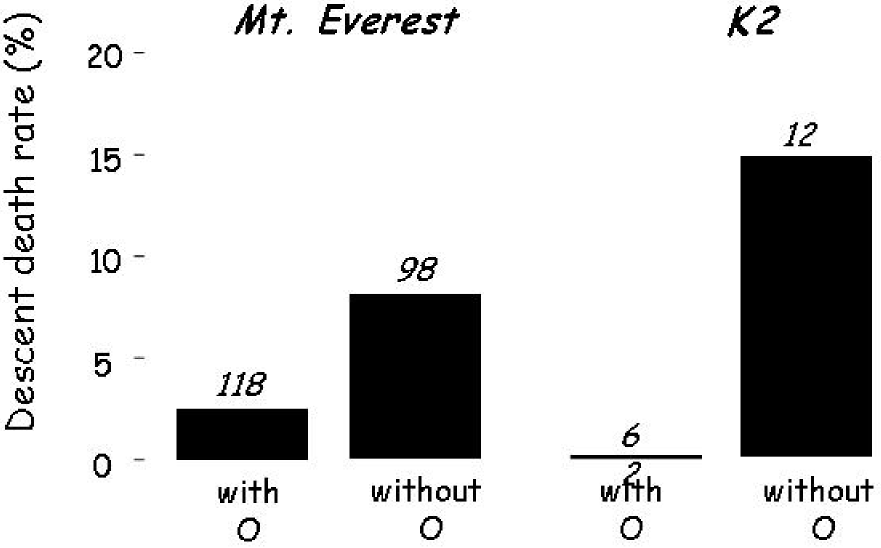

Figure 3. Death rates during descent from the summit of Everest and of K2 as a function of use of supplemental oxygen, with the number of individual summiters indicated (through 2000).

Death rates during descent were lowered when the 2000 data were added to the original data set, but the percentage changes are small. Death rates during descent are still significantly higher ($P < 0.001$) for climbers who did not use supplemental oxygen. This pattern remains significant even if one excludes deaths associated with two major storms on K2 in 1986 and 1995.

The statistical association between supplemental oxygen use and reduced death rate is strong, but does not necessarily imply cause and effect. Elsewhere we have outlined some alternative explanations of the patterns (4,7). For example, climbers who use supplemental oxygen use might survive better – not because of supplemental oxygen – but because they have better equipped high camps and Sherpa support in the event of a storm or medical problem (L. Reichardt, personal communication). Quantitatively evaluating such alternatives will require far more detailed data than are available at present.

We do note, however, that most of the deaths during descent on K2 and Everest occurred high on the mountain. Also, most of these deaths are from "falls" or "disappearances," which probably implies a fall (otherwise most bodies would have been found). This pattern would be consistent with the idea that climbers descending from a high summit are often at their physiological edge, such that the use of supplemental oxygen could be a benefit in promoting survival.

How does convective heat loss change with altitude?

The above analyses focus on mountaineering statistics. But a full understanding of patterns of success and of death require an appreciation of the physical environment at high altitude. Barometric trends are now well understood (29), but our knowledge of temperature and wind at extreme elevation is still rudimentary. Yet many deaths in the Himalaya are associated with storms (9). So we are also beginning to study variation in physical environmental factors (especially temperature and wind), and how they impinge on organisms at high altitude.

A major problem for Himalayan mountaineers is convective heat loss, which influences wind chill and the resultant risk of hypothermia and frostbite (22). Although convective heat loss obviously increases with altitude, the relationship between altitude and convection is biophysically complex. Increased wind speeds and decreased air temperatures at altitude (16) will increase convective heat loss. However, air density declines dramatically with altitude (by ~ 60% from sea level to 9000 m) and will have the opposite effect on convection (C. Houston, personal communication). Thus, do equations using sea-level densities of air significantly overestimate heat loss ("wind chill") at altitude? This evaluation requires a biophysical analysis of heat flux (22).

We have made an initial exploration of this issue. The model estimates the heat flux density for an exposed human face, assumed to be flat and parallel to the wind, have a diameter of 15 cm, and a fixed skin temperature of 36°C (18)). Empirically derived relationships were found for input variables that vary with altitude or temperature or both (air pressure, specific heat capacity, thermal conductivity, and dynamic viscosity (3,12); and heat flux was calculated for various combinations of altitude, wind speeds, and air temperatures.

Figure 4 shows convective heat loss at different wind speeds and altitudes. At any given wind speed, predicted convective heat loss is (not surprisingly) much higher at 9000 m than at sea level, primarily because air temperature drops steeply with altitude (~ 6.5°C/1000 m). However, the counter impact of declining air density ("ρ") is nonetheless strong. To show this, we plot the predicted heat loss for a air temperature appropriate for 9000 m, but with an air density appropriate for sea level (dashed line in Figure 4). This pattern may provide some consolation to mountaineers – the wind chill isn't as bad as it could be!

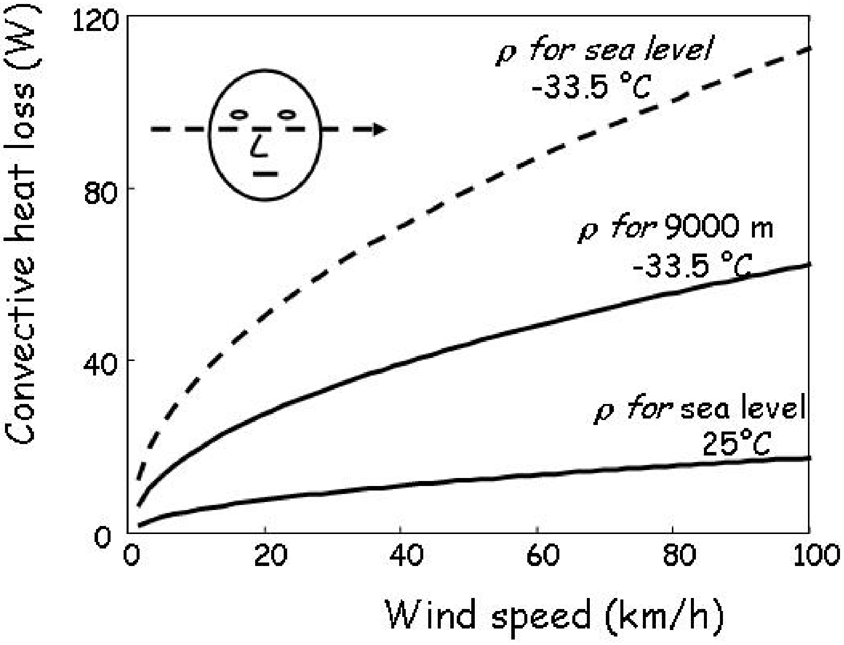

Figure 4. Predicted convective heat loss at different wind speeds, air temperatures, and air densities.

Weather and storms

The impact of storm on Himalayan mountaineers is well appreciated, at least in a subjective sense. However, no quantitative study has yet related weather patterns to death or success rates. An obvious reason is the lack of standardized weather data for the mountains themselves.

An important innovation in this regard is the establishment of a high-altitude weather station by the Department of Applied Hydrobiology of the Italian National Research Council (23). The Pyramid station (5050 m) near Mt. Everest was established in 1990 at the confluence of the Lobuche and Khumbu Glaciers, just a few kilometers WSW of Mt. Everest. This station records air temperature, wind speed and direction, relative humidity, precipitation, and barometric pressure at 2-h intervals. Potentially such weather stations may be able to provide advance warning of approaching storms. Moreover, time-series analyses can potentially reveal unexpected patterns. For example, a recent analysis of data from a Tibetan station (4302 m) revealed a biennial cycle of winter precipitation (2). Such information could be extremely useful to climbers trying to decide when to schedule trips.

Long-term weather data will also provide information on the probability of storms. For example, was the infamous ’96 storm on Everest a freak event, or do storms of similar magnitude occur there regularly? As the Pyramid data base grows, quantitative answers to such important questions will be possible.

CONCLUDING REMARKS

We have shown that quantitative analyses of mountaineering in the Himalaya often reveal conspicuous patterns. At a minimum level, those analyses can be useful in validating – or contradicting – conventional wisdom as to what is safe or dangerous. Moreover, those analyses can provide tests of predictions deduced from basic physiological data. In two cases presented here, analyses were consistent with those predictions. However, in both cases, we have had difficulty testing for possible confounding factors. Thus, the best we can do is to say that the data are consistent with expectations, but we are unlikely to assign rigorously cause and effect. Even so, the emergent patterns may provide valuable information to climbers themselves.

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