Physiological Studies

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The body is a remarkably well-regulated assembly of biological machinery. Under ordinary conditions it looks after the proper balance of its internal affairs with a precision and reliability that any automation engineer could envy. Within limits, it also actively accomodates itself to circumstances somewhat removed from the ordinary, among them cold, heat, altitude, exercise, and disease. Man probably has been aware of these elementary facts from the time he first evolved human insight,but physiological regulation under normal and abnormal conditions still remains a compelling subject for scientific research. For the most part only the effects have been described while much of the underlying mechanism remains obscure.

Men engaged in climbing the highest mountains are in some respects unique subjects for research on the body's regulatory mechanisms. Driven by intense motivation climbers voluntarily subject themselves for extended intervals to submarginal environmental conditions and discomforts that would not long be tolerated by subjects in a contrived laboratory setting. Prolonged exposure to severe hypoxia (oxyten deficiency) combined with fatigue, cold, insomnia, diminished appetite, and psycogenic factors must ultimately lead to a state of maximum acclimatization, and then beyond to progressive deterioration when physiological reserves for adjustment are exhausted and the crucial balances in the body's functions and chemistry can no longer be maintained. These are conditions that may evoke in our regulatory machinery informative responses ordinarily inaccessible to study.

With this in mind, the studies on Mt. Everest were designed to examine some of the characteristics and responses of two of the body's vital components, one of which responds specifically by altitude, whereas the other plays a key role in the adjustments that are made to meet stressful conditions generally. The first involves the blood and more specifically the production of red blood cells. The subject of the second part of the study was the adrenal gland and its multitude of hormones that help regulate many of the body's functions, metabolic processes, and chemical balances.

Before the Expedition took to the field, two laboratory studies were needed to give meaning to observations made on the climbers during the ascent of Mt. Everest. In one of the two tests, normal values of physiological parameters were determined for each member of the team at sea level. Without these "base line" values, data gathered later at high altitudes would have no points of reference and therefore little meaning. These measurements were made at the Donner Laboratory, University of California, a month before the teams departure.

The second test was more elaborate and somewhat different in nature. It was designed to bring out the differences in responses evoked by sudden exposure to altitude as compared to those experienced by a man going slowly to the same altitude, hence acclimatizing as he went. The approach march to Mt. Everest takes three weeks or longer, long enough for acclimatization to be well advanced by the time Base Camp is reached. For comparison, a member of the Expedition was rapidly decompressed to 17,000 ft in the Donner Laboratory high altitude chamber and kept at this altitude for four days. Before, during and after his incarceration his reactions were constantly assessed with batteries of physiological and biochemical tests, and clinical observations. In general, the responses to sudden exposure to altitude are far more dramatic the first few days than one encounters in climbing high peaks, even when the peak is Mt. Everest. A few of the differences are brought out later.

Among physiological responses to high altitude, the "thickening" of blood is probably one of the most familiar. The thickening is solely the result of an increase in thenumber of red blood cells (erythrocytes); the plasma volume does not change appreciably. In the healthy person at sea level about 0.8 percent of the red cells are replaced per day. New cells formed in the bone marrow are balanced by removal of old red cells from the circulation. Thus, nearly a constant and "normal" total volume of about 35 cubic centimeters of red cells per kilogram of lean body weight is maintained. Ordinarily, red cells make up 40 to 50 percent of the blood volume, and hemoglobin, the red pigment that carries oxygen, amounts to 14 to 16 grams per 100 cubic centimeters of blood.

Under the stimulus of hypoxia, red cell production increases. Precisely how this happens is still obscure except that it is known to be mediated by an elusive hormone called erythropoietin. The amounts of erythropoietin normally circulating in the blood and excreted in the urine, even at moderately high altitudes, is too small to be detected by the relatively insensitive assay methods available. However, the hormone is sometimes found in high concentrations in persons with very severe anemia, and it is readily detected in laboratory animals during the first two or three days they are exposed to high altitude. A similar response for man was demonstrated in the expedition member who was acutely decompressed to 17,000 ft in the high altitude chamber. A significant result of that test was the observation that erythropoietin and the severe symptoms of altitude sickness subsided together after three days at altitude.

In pursuing this investigation on Mt. Everest there was no expectation of finding erythropoietin in men acclimatized to the elevation of Base Camp. Climbers who ascended from Base Camp to camps at 23,000 ft within the space of a few days seemed the most promising candidates for demonstrating an acute response such as we had seen in the chamber test. Moreover, in the interest of learning if erythropoietin ever remains consistently elevated, climbers who spent extended intervals at 21,400 ft and 23,000 ft were also tested. For the climbers the procedure was simple, they merely collected urine in a bottle for a day. When the bottles were returned to Base Camp the urine was passed through special filters to concentrate the hormone for later assay in the laboratory.

Research conducted in a tent is never so impersonal as it frequently is in the laboratory. In some respects this was regrettable. The special filters for processing the urine would tolerate neither drying nor freezing. Storing them in quart bottles of water solved one problem but more heroic measures were needed for the other. Sharing a sleeping bag every night with three or four hard, cold, and sometimes damp bottles seemed at times an inordinate sacrifice in the name of science.

Negative results are always anticlimactic even when they are meaningful. This was the case for erythropoietin. None of the climbers who were tested had produced measurable quantities of the hormone. In contrast, it may be recalled, the subject in the pre-expedition chamber test produced a high concentration of erythropoietin at only 17,000 ft, but he did this only when symptoms of hypoxia were extemely severe. Such symptoms were never as severe on Mt. Everest as those observed in the chamber. For reasons that are still not entirely clear, climbers never experienced the same degree of "tissue hypoxia", even at the highest altitudes on Mt. Everest when they ran out of oxygen, that they might have suffered had they been brought suddenly to Base Camp from sea level.

Although erythropoietin evaded detection, it was unquestionably there in greater than normal concentration prodding the bone marrow into ever greater production of red cells with increasing altitude. Fortunately the production rate could be measured with somewhat greater confidence than the stimulating hormone. Iron is the key element in hemoglobin, the red pigment that forms sixty percent of the red cell. When more red cells are manufactured, correspondingly more hemoglobin is synthesized, and more iron utilized. It is a long but reasonably direct chain of events from iron to circulating red cell; hence, if the rate of use of iron is measured, as it can with radioactive iron, the production of red cells can be estimated. In principle the method is simple; the subject's own plasma is labeled with radioactive iron, injected back into his veins, and then blood samples are taken at intervals for several hours to determine how rapidly the radioactivity is removed from the plasma to form new hemoglobin. With a portable counter generously provided by Nuclear-Chicago Corporation, measuring radioactivity on the slopes of Mt. Everest was no more difficult than making a pot of tea.

This was never a popular test and the ready willingness of team members to cooperate was gratifying. The victim spent the better part of a day confined to camp with a four-inch long needle with a stopcock set in a vein in his arm, much the same as a spigot in a cask. With all its complications and discomforts--when done in a small tent on snow--the experiment was highly informative. It showed that at 17,800 ft man produces red cells nearly twice as fast as at sea level, and at 21,400 ft his production rate is 2.5 to 3 times as fast. It also showed that the total volume of red cell had expanded 50 percent and that the plasma volume had not changed.

Conventional blood tests, unlike that with radioactive iron, could be made repeatedly to follow the changes in red cell concentration as the team progressed to higher altitudes. Hemoglobin, for example, followed roughly the gross pattern of increasing altitude but with a two week delay. However it never exceeded 24 grams percent (normal: 14 to 16). The moment the Expedition left Base Camp on the return march, the response was immediate. Hemoglobin concentration dropped precipitously. The body simply stopped producing red cells when informed by the drop in altitude that we were returning to Kathmandu--where iron in the blood is needed less than castiron in the stomach.

The adrenal glands are two small flattened bodies perched, one each, atop the kidneys. The inner portion (medulla) of these bits of tissue secrete adrenalin, the "panic" hormone that gives us a momentary boost when suddenly confronted with danger. However, it was the outer layer, the cortex of the adrenal gland, and more particularly its multitude of hormones that commanded the attention of the physiological studies. Among the many hormones secreted by the adrenal cortex, one of the most important is the familiar substance hydrocortisone.

The importance of the adrenal cortex as a regulatory organ is firmly established. The cortical secretions, some of which are controlled from the pituitary gland by ACTH, exercise a strong and often controlling influence over the body's chemistry, the heart, and the circulatory and respiratory systems. In response to such challenges as disease, injury, environment, or psychogenic factors that tend to disturb the body's normal physiological balances, it is the adrenal cortex that acts to restore equilibrium. Until the balance is restored, according to one widely held view, a state of stress exists that manifests itself in physiological, chemical, and psychological changes that may be profound. Physiological reserves that can be called upon to meet a challenge may seem large but they are also limited. If the demand continues beyond the capacity to adjust, deterioration and ultimately death ensue. The extreme conditions encountered in Himalayan climbing made it reasonable to assume that Mr. Everest would induce in her assailants an advanced state of stress and thus provide the rare opportunity to observe how and to what extent the adrenal cortex copes with such problems.

The cortical hormones are excreted, some in slightly modified form, in the urine, making their collection easy for the investigator and painless for the subject. Once more, as in the search for erythropoietin, the quest for urine was pursued over the faces and ridges of Mt. Everest. The Sherpas could well understand our using bottles in camp at night, but carrying the bottle while climbing perplexed them, and carrying the full bottles back to Base Camp was beyone all comprehension. Twenty-four hour collections were obtained under a variety of circumstances, all of them, we felt, involving stressful conditions. At the end of the first day's collection the climber received an injection of ACTH to stimulate his adrenal glands to maximum output of certain members of the hormone group, among them hydrocortisone. The second day's urine collection would then reveal his adrenocortical reserve. Such collections were obtained from nearly all the summit climbers, their support teams, and from men living at 21,400 ft and 23,000 ft for prolonged intervals. Before revealing what was found in this accumulation of fluids, a few observations on some of the collateral tests are needed.

Basal pulse rate and resting blood pressure increased as expected almost immediately as the Expedition moved to higher elevations on the approach march and they remained higher than normal for several weeks after arriving at Base Camp. But as acclimitization progressed, pulse and pressure slowly returned to the values they had at sea level. The pulse or systolic pressure, or both, for some climbers ultimately dropped below their normal values although diastolic pressures always remained higher than normal in everyone.

The response of the heart and circulation to moderate exercise was tested by observing the rise and recovery in both pulse and blood pressure following a three-minute step test. The general character of the recovery pattern did not seem to change much during the course of the expedition, although there were exceptions. However, the rise in pulse and pressure produced by the exercise changed progressively with acclimatization. In the first week at altitude, when symptoms of hypoxia were most evident, the responses were greater than at sea level. During the two months that followed, the pulse and pressure responses to the exercise decreased steadily until they were decidedly smaller than they had been in the pre-expedition test. The cardiovascular system had obviously made important adjustments to meet the challenge of hypoxia.

Crude estimates of muscular strength were made from time to time with an instrument that measured hand grip. If changes in strength occurred they could be seen in the maximum force the man could exert and the duration that one half the maximum force could be held. Some improvement occurred initially, probably the result of "training" in the use of the device, but no significant impairment of strength as measured in this manner developed later in the course of the Expedition as had been anticipated. In contrast to this, most members of the team felt their capacity for heavy work was significantly reduced by the time Base Camp was abandoned. Subjective observations of this kind often contain a large measure of truth but they are always difficult to assess; they are compounded of many unweighable factors and subject to no small measure of unintentional self deception. We can only report the existence of this effect as a conviction, although there is indirect support for it.

Climbers around the world are acutely conscious of the need to maintain fluid balance because of the debilitation and hazards that accompany dehydration. The American Expedition subscribed to the rule followed by the British Mt. Everest Expedition in 1963 at the urging of Dr. L. G. C. Pugh that each man must have five to seven pints of fluid per day. Apparently the rule was practiced as well as preached because there were few signs of chronic dehydration. The inevitable exceptions were acute in nature, involving primarily the summit climbers who had no practicable means of securing fluids during the 12 to 20 hours they were above the highest camps when fluid loss, unfortunately, was greatest and most critical.

Nutrition has received if anything more emphasis than proper hydration, but it is far more difficult to manage in practice. The principles are clear enough but they cannot resolve the practical problems of logistics, limited acceptibility of highly processed foods, appetites that both diminish and become more selective with increasing altitude, and perhaps certain insidious effects of hypoxia about which little is known. With more than sufficient experience in semi-starvation on previous expeditions, and no desire to repeat it, we were determined to have ample quantities of food, particularly foods high in protein, and in such limitless variety that even the most jaded appetite could not help but find something appealing. The result was without doubt the most elaborate menu ever offered on Mt. Everest.

In spite of an elaborate and well stocked larder, weight loss during the Expedition followed a familiar pattern. The ten to fifteen pounds everyone lost on the approach march could well be spared. Exact measurements of fat, water and protein made on members of the team in the pre-expedition laboratory tests showed that fat constituted one-eight to more than one quarter of their weights. Weights stabilized before Base Camp was reached and for a week after arrival, but once again weight loss resumed its persistent course when men moved to higher camps. Much of the weight loss during the ascent was unquestionably fat, whose loss would do relatively little harm, but convincing signs of muscle wasting became evident even before fat reserves were exhausted. The debilitating effects of lean tissue wasting on health and physical performance are well known. It would seem much the wrong condition in which to enjoy climbing Mt. Everest.

It is now evident that in the operations above Base Camp everyone suffered for want of protein as well as total calories. Depressed appetites, the ever present difficulties of preparing foods, and occasional food shortages could perhaps explain the weight losses without further inquiry. However, two additional factors may be far more important than we have heretofore realized. Monotony of diet for one can have devastating results, particularly under stressful conditions.

Highly processed concentrated foods seem to have this quality built into them. This is less true of some fats and carbohydrates, butter and sugar for example, but processed protein foods, especially meat products and concentrates, seem with continued use to lose much of whatever acceptability they may have had at the outset. In contrast, unprocessed foods of almost any description, old tough goat, eggs of doubtful vintage, and local potatoes were always consumed with keen appetites. Perhaps it was only the contrast and change that stimulated appetites, but it is also possible that under hypoxic conditions low acceptability of highly processed foods could contribute significantly to the weight loss and debilitation suffered by most high altitude expeditions.

There remains a second facet of nutrition at high altitude about which little is known. This concerns the absorption and utilization of food we do manage to consume. If hydrolysis of fats and proteins in the gastrointestinal tract is impaired, or if absorption of digested food in theintestine is impeded, then one could starve in the midst of plenty. Malabsorption or faulty metabolism could be a more insidious factor with greater and more persistent influence on health and performance than depressed appetite and fusyy preferences in food. Even forced feeding, as conscientiously practiced by Hornbein and Unsoeld, would then be of little avail.

Evidence to support this contention, admittedly, is both meager and contestible. It consists for the most part of non-specific signs and symptoms such as the steadily declining weights even when food consumption seemed adequate; the distressingly large quantities of gas in the gastrointestinal tract soon after eating, suggesting faulty digestion; and bulky perhaps abnormal stools daily even during protracted periods of inactivity. There can be little doubt but that everyone on the Expedition suffered from undernutrition, and it is likely that those who spent much time above Base Camp were also subjected to malnutrition.

Nothing in the data collected on Mt. Everest, however, makes it clear which of the factors discussed above is mainly responsible; probably all are involved to some extent.

If for no other reason than the appalling environment at high altitudes, one would expect in men climbing Mt. Everest an advanced state of stress that all but exhausted their physiological resources. The feeling of chronic exhaustion, the slow and painful effort even the smallest task demands at high altitude would seem to attest this. Certainly the appearance of the summit climbers on their return would suggest it. Moreover, there is a widespread conviction among authorities on the subject that the limiting altitude to which man can acclimatize lies somewhere between 20,000 and 22,000 ft. Beyond this he deteriorates progressively faster with altitude. No one would argue that without oxygen life expectancy 29,000 ft could be anything but short.

Yet the pages of physiological data from the Expedition seem to form a picture somewhat different from the one we had anticipated. We have looked through the test data in vain for unequivocal evidence of physiological stress that could be called severe, and for most of the men, even moderate. Certain of the white blood cells that often signal the existence of stress are unchanged; the cardiovascular responses to exercises are much the same as for team members who remained at the lowest camps, and all show good acclimatization; and the key electrolytes, sodium, potassium, and chloride, in blood and urine are all within the normal range. Finally, and most damaging to preconceived ideas, the adrenal cortex seems little disturbed by the experiences on Mt. Everest. The assays of the adrenocortical hormones are incomplete at the time this is written but the data at hand show little that is abnormal in the excretion rates of the hormones. The adrenal cortex also responds in a normal healthy manner to ACTH. Exceptions and differences exist, but no one is near the brink of physiological disaster.

Conclusions drawn before the results of a study are fully assessed are extremely hazardous and rarely offered. If compelled however to voice at least an impression that at this point seems to sum up the observations, it would have to be this: the climbers were physically debilitated by the time they left Mt. Everest, but they exhibited few signs of physiological stress. The Expedition, probably like those before it, seems to have been the victim mainly of semi-starvation, and we do not know why.

A final note is added here on a subject that was not part of the physiological studies but is nevertheless relevant to this Expedition and perhaps all others with 8000-meter-peak asperations. The possibility that the central nervous system, particularly the higher brain centers may be damaged by exposure to extreme altitudes is frequently discussed, occasionally debated, but rarely if ever brought under scientific scrutiny. Throughout the history of Himalayan climbing there is from time to time suggestive evidence of brain damage, in some instances perhaps permanent, in climbers exposed to altitudes greater then 8000 (26,250 ft) meters without oxygen. The effects are said to be expressed as impaired memory and personality changes, particularly chronic depression.

The six climbers of the American Expedition who reached the summit of Mt. Everest spent intervals ranging from four to twelve hours without oxygen above 28,000 ft, and four exhausted their oxygen on the summit. All told, eleven men, excluding Sherpas, climbed higher than 27,000 ft. Everyone appeared to experience acute psychic effects of hypoxia at the time, but once the Expedition left the mountain no apparent evidence of brain damage could be seen from casual observation. During the months that followed, however, many members of the Expedition have reported subjective signs of memory impairment, and some have experienced periods of depression. A variety of other, less well-defined symptoms, have also been described. In one respect their reports are identical: they have frequent difficulty in recalling once familiar names, and a need now to search out words that formerly were often and easily used.

On the basis of these subjective impressions it is not possible to assess the nature, extent and duration of cerebral injury, or even to assert unequivocably that it exists. If the evidence in climbers is less than overwhelming, there is still reason to believe brain damage is possible, even probable, at extreme altitude if for no other reason than the well known intolerance the brain has for anoxia. One conclusion is incontestable: the subject needs more study and less conjecture. It is one that future expeditions might well pursue in the interest of the welfare of high altitude climbers.

As every scientist knows, it takes funds as well as effort to do research. Or to paraphrase a quotation from "Rum Doodle" often used on the Expedition, "Gathering data is one thing, supporting it is quite another". For the task of gathering physiological data, support was gratefully received from the U.S. Atomic Energy Commission through the Donner Laboratory, University of California, and as research grants from the National Science Foundation, the U.S. Air Force Office of Scientific Research, and the National Aeronautics and Space Administration.