Book Reviews

Humans at High Altitude

High Altitude and Man. JOHN B. WEST and SUKHAMAY LAHIRI, Eds. American Physiological Society, Bethesda, Md., 1984 (distributor, Williams and Wilkins, Baltimore). viii, 199 pp., illus. $39.

The ascent to the summit of Mount Everest (altitude 8848 meters) by two climbers in 1978 without the use of supplemental oxygen renewed the curiosity of physiologists about the effects of extreme hypoxia on human function and performance. One result was the 1981 American Medical Research Expedition to Everest, under the leadership of John West. This expedition was unique not only in its principal objective of measuring human physiology at altitudes over 8000 meters but also in its complement of climbers, which included six physician-scientists who were responsible for obtaining data at extreme altitudes, including the summit of Mount Everest. The physiological research performed during the expedition forms the framework for the 16 research papers that make up this book.

The ability of humans to survive at high altitudes depends upon a series of adaptive changes in the oxygen transport chain, which delivers oxygen from the atmosphere to the cells of the body. Extrapolations of previous measurements at high altitudes to the altitude of the summit of Mount Everest led researchers to think that it would be unlikely that the oxygen transport chains of humans could adapt sufficiently to permit them to reach the summit breathing ambient air.

Perhaps the most interesting findings of the 1981 expedition were those that explain why this prediction was wrong. First, the barometric pressure measured at the summit (253 mmHg) was 17 mmHg higher than that of the International Civil Aviation Organization Standard Atmosphere for this altitude. This discrepancy arises because of the weight of a mass of cold air in the stratosphere above the equator. As pointed out by West, "This climatic idiosyncrasy makes it possible for man to reach the highest point on earth while breathing ambient air."

Second, unlike the elite endurance athlete at sea level, whose ventilatory responses to chemical respiratory stimuli are advantageously low, the climber to extreme altitude has a normal or even high ventilatory response to hypoxia, both at sea level and at high altitude. Although this degree of hypoxic responsiveness exacts a price in increasing the work of breathing and in a sensation of breathlessness, the high ventilation it induces at altitude maintains a critical alveolar P_{O_2}. In fact the alveolar P_{CO_2} measured at the summit of Mount Everest was an astonishing 7.5 mmHg, compared with a predicted value of 10 mmHg. This additional level of alveolar ventilation maintained the alveolar P_{O_2} at 35 mmHg, resulting in a calculated arterial P_{O_2} of 28 mmHg, considerably higher than it would otherwise have been. Indeed, at these extreme altitudes there was essentially a vertical relationship between barometric pressure and ventilation, such that with increasing altitude alveolar P_{CO_2} decreased sufficiently to prevent any further decrease in alveolar P_{O_2} despite the falling barometric pressure.

Finally, the respiratory alkalosis induced by extreme hypoxia was never compensated by the loss of bicarbonate to the extent that was predicted. As a result the calculated arterial *p*H on the summit of Mount Everest was an astonishing 7.76. This extreme alkalosis produced a marked shift to the left in the oxygen-hemoglobin dissociation curve, thereby enhancing the loading of oxygen onto hemoglobin in the lung and resulting in a calculated arterial oxygen saturation of 75 percent at the summit, a value that was considerably higher than expected.

Taken together the higher barometric pressure, the higher level of alveolar ventilation, and the higher arterial oxygen saturation prevailing at the summit of Mount Everest permitted a maximal oxygen uptake during breathing of ambient air that was substantially higher than predicted, and slightly above the basal oxygen requirements. As West states, "The evolutionary pressures responsible for man being just able to reach the highest point on earth are certainly obscure" and may belong as much in the domain of philosophy and theology as in that of science. Nevertheless the differences between the measured and predicted values at the summit of Mount Everest are the essence of science and make this volume an exciting and valuable work for physiologists and physicians. Particularly unusual are the six chapters of the first section (Man at Extreme Altitude), which describe in detail the physiological measurements made en route to the summit and on the summit.

In contrast to the physiological adaptations to hypoxia made over a period of weeks by lowlanders ascending to high altitude, the adaptations undergone by natives of high altitudes have a time course that spans years, and even generations. In some instances different strategies appear to have been utilized by high-altitude natives in the Andes, the Sherpas of Nepal, residents of the Tibetan Plateau, and individuals living high in the American Rockies. The similarities and differences of these groups form the basis for four interesting chapters in a section entitled Physiology of Permanent Residents of High Altitude.

The short-term and long-term physiological responses to hypoxia are not always adaptive. Two of the more common (and possibly related) disorders associated with high altitude are chronic mountain sickness and disturbances in breathing pattern during sleep that disrupt both pulmonary gas exchange and sleep structure. Six of the chapters in the book are devoted to the possible mechanisms underlying periodic breathing during sleep. With the exception of a chapter by Lahiri and colleagues (demonstrating a relationship between hypoxic sensitivity and periodic breathing at high altitude), these chapters are reviews of studies that were not part of the Everest expedition. However, the chapters are relevant to the problem of breathing during sleep at high altitude and broaden the scope of the book beyond those experiments that could be conducted on Mount Everest.

The American Medical Research Expedition to Everest was a magnificent success and bears eloquent testimony to the extremes to which scientific curiosity can spur human endeavor. *High Altitude and Man* encapsulates the essence of the expedition and establishes that it brought physiological measurements "to the highest levels."

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