LESSONS FROM HISTORY

Research at the Extremes: Lessons from the 1981 American Medical Research Expedition to Mt Everest

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“Naturally it would be interesting to have information on the arterial PO_2 of a climber on the summit. Unfortunately it is impracticable to take arterial blood under these conditions . . . ”¹

On October 24, 1981, Chris Pizzo and Yong Tenzing, members of the American Medical Research Expedition to Mt Everest (AMREE), stood on the highest point on earth and collected 6 alveolar gas samples. These, together with further data collected from the South Col (8050 m), provided the foundations for what is surely one of the most unique field experiments ever undertaken—the calculation of arterial blood gases from a mountaineer on the summit of Mt Everest (8848 m; Table).

Without the accurate portable blood gas analyzers that many of us now take for granted, the AMREE team used the “Bohr Integration,” a complex computational method used primarily to calculate the diffusion capacity of oxygen inside the human lungs. By assuming this value, the AMREE team was able to calculate the mean alveolar-capillary PO_2 difference and therefore deduce the PO_2 of arterial blood. However, to complete this, a long list of measurements and assumptions would need to be made first, and it is this attention to detail that makes “Pulmonary Gas Exchange on the Summit of Mt Everest” such an exceptional piece of work.¹

In what Edouard Wyss Dunant, the leader of the unsuccessful 1952 Swiss Expedition to Mt Everest, once described as the “todeszone” or “death zone,” the AMREE team conducted an unparalleled set of tests. Not only did they record the first accurate barometric pressure reading on the summit of Mt Everest, but they were also able to obtain 42 resting alveolar gas samples from various sites above 8000 m (Figure 1). These results showed, for the first time, the dramatic fall in alveolar

PCO_2 that accompanies the high levels of ventilation typical for survival at extreme altitude. This fall in PCO_2 results in the maintenance of alveolar PO_2 at a somewhat higher level than expected, and therefore, “insulates as it were, the body from the progressively falling inspired PO_2 ” (Figures 2 and 3).² Despite the body’s efforts to optimize alveolar PO_2 , a recording of 29 mm Hg made by one of the team members at 8050 m (100 Torr being a typical sea level value) is testament to the extraordinary efforts these scientists undertook in order to complete their data collection!

The values obtained for alveolar PO_2 and PCO_2 could now be verified by inspecting their respective respiratory exchange ratios (R). Normally, these are calculated by dividing the volume of carbon dioxide produced by the amount of oxygen consumed. However, it is also possible to calculate R by using the partial pressures of each gas, provided the fraction (F_{IO_2}) and partial pressure (P_{IO_2}) of inspired oxygen are known:

$$R = \frac{PCO_2(1 - F_{IO_2})}{P_{IO_2} - PO_2 - (F_{IO_2} \times PCO_2)}$$

Normally, R lies between 0.7 and 1 and only rises above these values when an “unsteady” state is reached, such as during brief periods of anaerobic metabolism when oxygen is underused. Surprisingly, the mean value on the summit was calculated to be 1.49 and led the authors to conclude, “It is clearly misleading to quote the value of 37.6 Torr as the alveolar PO_2 on the summit since the R value was so high.”¹ Instead, the PO_2 was re-calculated by using the original PCO_2 of 7.5 Torr and an assumed R value of 0.85, giving a new, lower alveolar PO_2 reading of 35 Torr. Although anaerobic metabolism may explain, to some extent, the extraordinary R value, small errors in obtaining the alveolar PO_2 may have had a profound impact on the results. By identifying the error and addressing it, the AMREE team made a shrewd judgment that illustrates the team’s meticulous

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Alveolar gas and estimated arterial blood values on the summit of Mt Everest (8848 m)¹

Altitude (m)	Barometric pressure (Torr)	Inspired PO_2 (Torr)	Alveolar PO_2 (Torr)	Arterial			
				PO_2 (Torr)	PCO_2 (Torr)	pH	SO_2
8848 (summit)	253	43	35	28	7.5	>7.7	70
Sea level	760	149	100	95	40	7.40	97

approach and the inevitable problems that occur with data collection at such extremes.

On the morning after their successful summit bid, Pizzo and his colleague Peter Hackett undertook the difficult task of obtaining venous blood samples from one another. This procedure was performed in a small mountaineering tent on the South Col, a place that was once memorably described by members of the 1952 Swiss team as having, “the smell of death about it.” These samples were then transported in ice slurry down the mountain and processed at the AMREE laboratory in the Western Cwm (6300 m). Here, 3 essential pieces of information were obtained: the concentration of hemoglobin, the base excess, and finally, the value for PO_2 at which hemoglobin was 50% saturated (P_{50}).

Figure 1. Chris Pizzo obtaining an alveolar gas sample from the summit of Mt Everest (8848 m). At the end of a normal inspiration, AMREE team members would expire quickly and deeply through the mouthpiece and hold their breath for a second or so at residual volume. By pulling a lever on the alveolar gas sampler, the valve on the small pre-evacuated aluminum canister would open. Once the sample was collected, the valve could be closed by releasing the lever.¹ Photograph courtesy of J. B. West.

Despite the extent of their data collection, the AMREE team needed more information in order to complete the Bohr Integration. The sources for much of this dated back more than 20 years to the 1960–1961 Himalayan Scientific and Mountaineering Expedition. Under the leadership of physiologist Griffith Pugh, AMREE members John West and James Milledge obtained vital data from the “Silver Hut” experiments that allowed the equation to be completed.^{5,6} This information, together with later work,^{7–9} was scrutinized by West and Peter Wagner in their paper, “Predicted Gas Exchange on the Summit of Mt Everest” and incorporated into the calculation for arterial PO_2 .¹⁰ The assumptions they would make included the following:

1. At an altitude of 5800 m, the resting cardiac output in well-acclimatized lowlanders is unchanged compared with values at sea level.⁴ From this, a cardiac output of 6 L/min was chosen by the AMREE team, and values for resting oxygen consumption and car-

Figure 2. The alveolar PO_2/PCO_2 curve of acclimatized subjects first plotted by Rahn and Otis.³ At low alveolar PO_2 , hyperventilation leads to a marked fall in PCO_2 and the maintenance of the PO_2 at a value of approximately 35 mm Hg. Reprinted with permission.

Figure 3. Relationship between alveolar PO_2 and PCO_2 and barometric pressure in acclimatized subjects. Straight portions of the solid lines were first drawn by Fitzgerald in 1913 and extrapolated for lower barometric pressures (broken lines).⁴ However, solid curved lines indicate that values depart from linearity, with PCO_2 falling steeply at extreme altitudes and PO_2 tending to flatten out at a value of approximately 35 mm Hg. Reprinted with permission.

bon dioxide were calculated using an assumed value for R.

2. Pulmonary capillary blood volume is unaffected by altitude. As the transit time of blood in the pulmonary capillaries is calculated by dividing pulmonary capillary blood volume by cardiac output, this value also remains unchanged at altitude.⁷
3. The diffusing capacity of the blood-gas barrier to oxygen was assumed to be at least 40 mL/min/Torr.^{5,9}
4. The ventilation-perfusion inequality has a minimal effect at altitude and was subsequently ignored in the calculation.⁸

The work of Professor West and his AMREE colleagues shows that, despite enormous technical and logistical limitations, it is possible to undertake important

scientific work at the extremes of altitude. With marked improvements in compact, portable, and rugged computerized devices, it is now possible to undertake ambitious field research projects previously thought impossible. However it is this paper,¹ now almost 25 years old, that not only provides the inspiration but also sets the standard for all those who wish to undertake precise physiological measurements in the most hostile of environments.

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