High Altitude Physiology

**Hypobaric Hypoxia**

Within the troposphere

Barometric pressure \((P_b)\) ↓
as altitude↑ (vertical height above sea level)
as latitude↑ (Pb in poles<Pb in the equator)

Oxygen concentration remains constant
PIO2 decreases proportionately

Also decreases with lower temperature, inclement weather, and during winter
High Altitude Physiology

- **Hypobaric Hypoxia**

Low oxygen partial pressure due to hypobaria greatly hinders diffusion, and therefore reduces formation of oxyhemoglobin

(Duncan 2005)
Gradual decompression (e.g., from walking to altitude)

32% of climbers have hallucinations above 7500 m
MRI changes, including white matter hyperintensities and cortical atrophy above 7000 m
Memory retrieval impaired

Acute decompression (e.g., from aircraft explosion)

Everest (8848 m)
Aconcagua (6962 m)
Kilimanjaro (5895 m)
Mont Blanc (4808 m)
Ben Nevis (1344 m)

Symptoms vary among individuals and rate of ascent

PO₂ (mm/Hg) Altitude (m)
40 9000
50 8000
7000
6000
5000
4000
3000
2000
1000
0

Loss of consciousness
Dizziness or tingling
Altered night vision

Psychomotor impairment detectable with FTT/pegboard
Complex reaction time slows
AMS and HACE possible
Commercial aircraft are pressurised to an altitude equivalent of 1500-2500 m
High Altitude Physiology

Study of short-term changes that occur with exposure to hypobaric hypoxia (the acute response to hypoxia)

Studies of longer-term acclimatisation and adaptation.
High Altitude Physiology

• **Acclimatization**

Set of beneficial processes whereby lowland humans respond to a reduced inspired partial pressure of oxygen

Tend to reduce the gradient of oxygen partial pressure from ambient air to tissues (classical oxygen cascade)

Distinct from the pathological changes that lead to altitude illness
High Altitude Physiology

**Acclimatization Vs Adaptation**

Adaptation describes changes that have occurred over a number of generations as a result of natural selection in a hypobaric hypoxic environment.

High-altitude residents (Andes, Thibetan plateau)

Distinct from the pathological changes that lead to chronic mountain sickness (HAPH, ↑↑ HCT)
Acclimatization: Depends On

Degree of hypoxic stress (rate of ascent, altitude attained)

Intrinsic capacity of the individual
  (genetic and anatomic variation, medical conditions)

Extrinsic factors
  (eg, alcohol, medications, temperature)
High Altitude Physiology

The physiological responses to hypoxaemia and cellular hypoxia are poorly understood.

Inter-individual differences in performance at altitude and outcome in critical illness remain unexplained.
High Altitude Physiology

Hypoxic adaptive processes are likely to be common to tissue hypoxia whatever the cause, however, and studying healthy individuals progressively exposed to hypoxia through ascent to high altitude may inform of the nature of the hypoxic adaptive processes occurring in critically ill patients.

It might be possible, in other words, to take knowledge 'from mountainside to bedside'.

High-altitude physiology and pathophysiology: implications and relevance for intensive care medicine
Michael Grocott*, Hugh Montgomery and Andre Vercueil
Critical Care 2007,
Effects of Hypoxia

A condition in which the body as a whole or a region of the body is deprived of adequate oxygen supply.

Low oxygen pressure at high altitude

The carotid body, a cluster of specialized cells in the carotid artery, detects low oxygen levels in the blood and alerts the brain.

In response, the brain sends signals to the rest of the body to:

- Increase breathing rate and constrict vessels in the lung
- Increase heart rate
- Dilate peripheral blood vessels in arms, legs, hands, and feet
High Altitude Physiology

Acclimatization: Ventilation and PaO2

Increase in ventilation (hypoxic ventilatory response)

PCO2 level at which ventilation is stimulated is lowered (hypercapnic ventilatory response)

Hyperventilation results in a respiratory alkalosis
High Altitude Physiology

- **Acclimatization: Circulatory Changes**

  *Systemic Vasculatures*

  Increased sympathetic activity

  Cardiac output
  Blood pressure
  Heart rate
  Venous tone

  Stroke Volume
High Altitude Physiology

Acclimatization: Circulatory Changes

Pulmonary Vasculatures

Constriction in response to hypoxia

Increase in pulmonary vascular resistance and PA pressure
High Altitude Physiology

- **Acclimatization: Circulatory Changes**

  Cerebral Vasculatures

  CBF and oxygen delivery is generally maintained down to SpO2 levels of 70 to 80%

  Overall global cerebral metabolism is well-maintained during moderate hypoxia
High Altitude Physiology

- **Acclimatization: Hematologic Changes**

  Increased hemoglobin concentration ([Hb])

  In the first few days at altitude, [Hb] is increased due to plasma volume contraction

  Within a few hours, hypoxemia stimulates increased production of erythropoietin

  Increased thrombotic risk
Maximal oxygen consumption, maximal heart rate and stroke volume are all reduced after acclimatisation despite normalisation of the blood oxygen content to sea-level values (by an increase in haemoglobin concentration).

Furthermore, pure oxygen breathing by acclimatised individuals (which results in an oxygen content greater than that at sea level) does not return maximal oxygen consumption to sea-level values.
High Altitude Physiology

Oxygen carriage is not a limiting factor for maximal oxygen consumption at altitude

This could be consistent with central nervous system limitation of the maximal exercise capacity

With limitation of oxygen flux within the tissue
Or with a downregulation of cellular metabolism
ACCLIMATIZATION

MAINLY >3000m

ACCLIMATIZATION ITINERARY

ABOVE >3000m, SLEEPING ALTITUDE 330m

SLEEPING ALTITUDE REMAINS /3 D

IDEALLY ONE W BETWEEN 4000m - 5000m

«CLIMB HIGH SLEEP LOW»