Exercise at Altitude

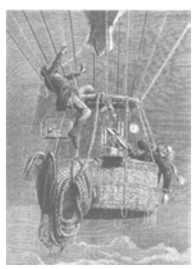
Khumbu Icefall: on the way to Camp 1 for Everest
1 mi, 2,000ft climb, 300ft crevases, < 4 hrs

Mallory: a story and a Mystery

- June 8, 1924, George Mallory and Andrew Irvine

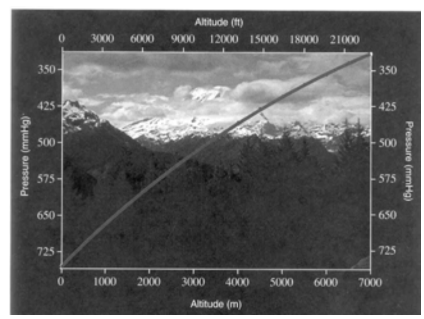
A little history

- Torricelli (1644) developed the mercury barometer
- Pascal (1648) Pb decreases with altitude
- Lavoisier (1777) oxygen and other gases contribute to Pb
- Bert (1880s) described effects of hypoxia
- 1875 first balloon fatalities



James Glaischer first to describe effects of hypoxia, 1862

Altitude and Pressure



1 meter = 3.28 feet
Albuquerque, ~ 1500 meters

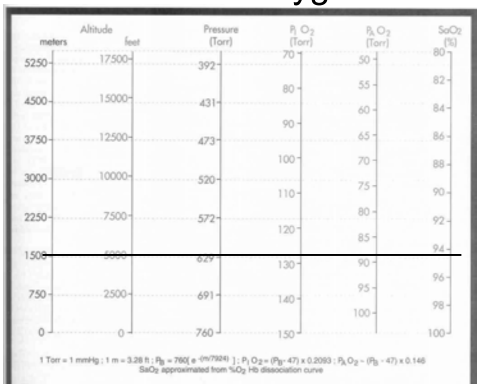
Altitude Definitions

- High altitude
  - 1500 to 3500m
- very high altitude
  - 3500 to 5500 m
- Extreme altitude
  - >5500m
  - 5820m is the upper limit of human habitation (~19,000 ft)

Ambient Pressure and oxygen

- (PO_2) = %O_2 x Pb - water vapor
- Sea level
  - PO_2 = 760-47 x .2093 = 149 mmHg
- Albuquerque (5200 ft)
  - PO_2 = 630-47 x .2093 =122 mmHg
- Pikes Peak (14,300 ft)
  - PO_2 = 430-47 x .2093 = 80 mmHg
- Everest (29,028 ft)
  - PO_2 = 250-47 x .2093 = 43 mmHg

Altitude and Oxygen Sat.

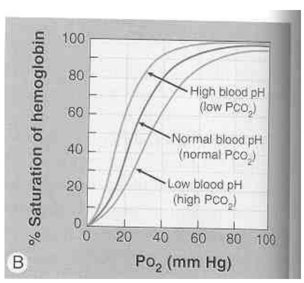


Acute Pulmonary Responses

- Hyperventilation (at 4300 m, Ve increases 30%)
  - caused by hypoxia (arterial chemoreceptors)
- $CO_2 + H_2O \leftrightarrow H_2CO_2 \leftrightarrow HCO_3^- + H^+$
    - decreases PACO2
    - decreases HCO_3^-
    - respiratory alkalosis
    - increases PAO2
  - shifts Hb dissociation curve left
  - pulmonary hypertension
  - Cheyne-Stokes breathing

Hemoglobin dissociation curve

- Alkalosis
  - left shift
  - greater O_2 uptake from air
  - less transfer to tissues
- 2,3 DPG
  - right shift



Acute responses: cardiovascular

- Decreased a-vO_2diff (decreases a)
- Increased resting and submax HR
- Decreased SV
  - Hypoxia, ↑ TPR, ↓ PV, ↑ HR
- increase in submax Q
- max Q decreases slightly or remains the same

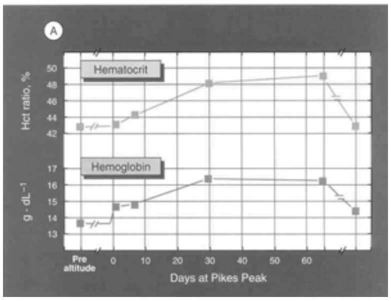
Acute Responses: body fluids

- Increased fluid loss
  - lower water vapor, hyperventilation, vasoconstriction, diuresis
- Reduced plasma and blood volume
- Increased hct and viscosity

Hypoxia-inducible factor

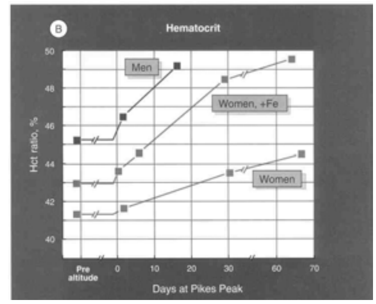
- Present in most cells and inactivated by the presence of O_2
- Hypoxia, HIF-1 is formed, moves to the cell nucleus, binds to a gene promoter
- Gene causes the transcription of mRNA for EPO
- Also transcribes mRNA for VEGF
  - vascular endothelial factor causes growth of new blood vessels

8 Women from Missouri



Hannon et al, JAP 1968

Men vs. women with supplemental Fe



Acclimatization: Body fluids

- Increased Epo from kidney (PO_2)
- polycythemia with no increase in BV
- Increased 2,3-disphosphoglycerate
  - Shifts hb dissociation curve back to the right
  - compensation for alkalosis
- Excretion of HCO_3^-
  - Restores acid-base balance

Acclimatization: cardiopulmonary

- Ve, further increases
  - Increased sensitivity of arterial baroreceptors
- PAO_2, further increase
- submax HR remains elevated
- submax Q falls, SV lowers
- max Q lowers
- some restoration of VO_{2max}
  - endurance trained athletes who live at altitude for years never regain their sea level VO_{2max}

Acclimatization: muscle

- Increased muscle capillarity
- reduced muscle fiber size
- increased mitochondria
- increased aerobic enzymes?
- increased reliance on carbs
- increased muscle myoglobin

- Body composition
  - loss of LBM and weight
    - increased BMR, extra 340 kcal/d

Native responses

- Oxygen-carrying capacity of HA Peruvians is 28% > sea level residents
  - smaller size with a larger chest (barrel)
  - increased heart size
  - larger lungs, more capillaries
- Monge's disease (Chronic Altitude Sickness):
  - persons who live at altitude
  - symptoms similar to altitude sickness
    - hct 80, blue lips, clubbed fingers
    - sludging of RBC
    - more common in men

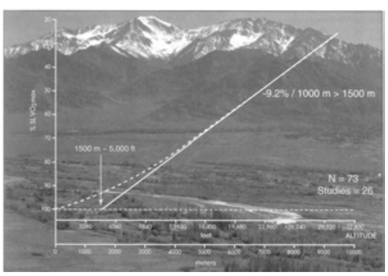
High Intensity Exercise

- for 10s max cycling, no effect
- sprint activities less than 1 min are not impaired at moderate altitude
- More prolonged intense exercise
  - decreased max lactate
  - increased acidosis
  - due to reduced HCO_3^- and buffering capacity?

VO_{2max}

- Decrease VO_{2max}
  - Proportional to reduction in P_b
- Decreased VO_{2max} is due to
  - reduced PaO_2
  - impaired O_2 extraction from muscles
  - decreased Q_{max}
    - due to decreased HR_{max} and SV_{max}

VO_{2max} and altitude



Above 1500m, VO_{2max} decreases by 9.2% each 1000m
> fitness > effect

VO_{2max} on Everest

- VO_{2max} decreases with altitude
- Individuals with a larger VO_{2max} will perform better at altitude (despite larger reduction)
- On Everest, VO_{2max} is reduced to 10-25% of sea level value
- Top of Everest is about the limit of functional work--VO_{2max} approaches resting VO_2
- Persons with exceptionally high VO_{2max} can summit without oxygen
  - 1978, Messner and Habeler were the first

Cardiorespiratory Endurance

- Decrease in VO_{2max} and increase in blood lactate independently decrease tolerance to prolonged exercise
  - time trials at 1-3 miles at 2300m were 2-13% slower

Cardiovascular Responses to Submaximal Exercise

- Greater increase Ve
- Increased VO_2 (work of breathing)
- Increased HR
- Decreased SV
- Increased Q (lower a-vO_2diff)
- No change muscle bf (increased hct)
- Increased blood lactate

Metabolic Response to Exercise

- Higher lactate during submax exercise, but < lactate at max
- No change in LT at given $\%VO_{2max}$
- Greater reliance on carbs

Lactate Paradox

- decreased maximal lactate after chronic altitude exposure
  - due to increased lactate uptake by active and inactive skeletal muscle, the heart, kidney, and liver
  - reduced ability of CNS to support exercise, lower maximal work intensities
  - reduced ability to mobilize glucose and thus form lactate (McArdle, pg 452)

Mexico City Olympics

- 1968 Olympics in Mexico City
  - altitude of 2300 m, Pb 569 mmHg
- Beneficial effects
  - jumping, throwing, sprinting
- Negative effects
  - running distances > 1mile
- Sparked interest in best ways to train

Benefits of moderate altitude acclimatization

- Natives to moderate altitude (2000m) experience fewer problems with exposure to higher altitude (4300m)
  - less mountain sickness
  - 1/2 decrement in VO_{2max}
  - larger maximal Ve

Time for acclimation

- 2 wks to adapt to 2300m
- thereafter for each 610m increase in altitude, 1 additional wk up to 4572m

Altitude Training Questions?

- Can altitude living improve altitude performance?
- Can altitude living improve sea level performance?

Altitude living and altitude performance

- No doubt, altitude exposure improves altitude performance
  – increases hct and hb concentrations
  – increases VO_{2max} 5-10%

Altitude training to improve sea level performance?

- Mixed results
  – 2300 to 3300m training for 2 wks improved 1500m and 1 mile race times at sea level
  – 3100 to 4000m training for 20-63d produced slower sea level times and decreased VO_{2max}
- To obtain benefits, training must be done at low or moderate altitudes
- At higher altitudes athletes can't train well and times will be reduced

Live high and Train Low

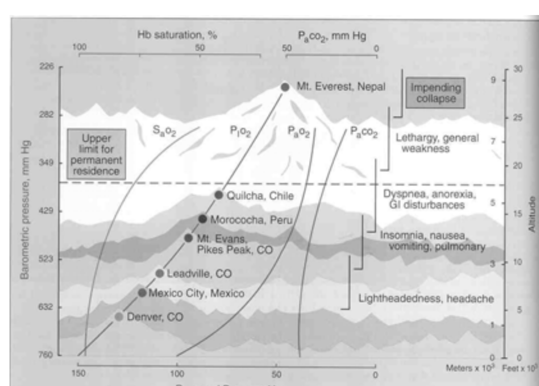
- Train at lower altitude to optimize work outs
- Athletes who lived at 2500m but trained at 1250m had greater increases in 5000m run than
  – athletes who lived and trained at 2500m
  – athletes who lived and trained at sea level

Sea level altitude training

- Normbaric hypoxia
  – increase inspired nitrogen during training
  – hypoxic sleeping tent
- Hypobaric chambers

Altitude Illnesses

- Ravenhill Br. physician 1913
  – first categorized types of altitude illness in the Andes
- AMS, Acute mountain sickness
- High altitude pulmonary edema (HAPE)
- High altitude cerebral edema (HACE)
- Each vary with the rate of ascent and individual susceptibility



Acute Mountain Sickness

- Symptoms
  - headache, nausea, vomiting, dyspnea, insomnia
  - begins 6 to 96 hrs at altitudes > 3000m
  - 0.1 to 53% at altitudes from 2400 to 5500 m
  - 6.5% men, 22.2% women at 2400-3400m
  - 80% at 4200m

HAPE

- Rapidly ascend > 2700m
- 2% of people in 12 to 96 hrs
- fluid accumulation in lungs interferes with gas exchange, from pulm htn
- cough, pink frothy sputum, rales
- shortness of breathe, extreme fatigue
- cyanosis, confusion, loss of consciousness
- more often in children and young adults
- give oxygen and DESCEND

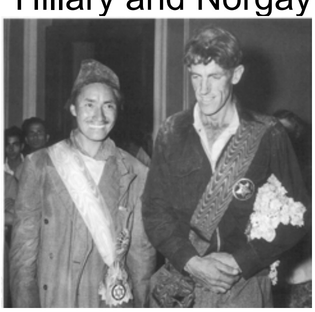
HACE

- Fluid accumulation in the cranial cavity
- hypoxia causes vasodilation of cerebral blood vessels
- 1% of people > 2700m
- mental confusion, coma, death
- most cases at >4300m
- give oxygen and DESCEND

Prevention of Altitude Illnesses

- Gradual ascent
  - no more than 300m/d above 3000m
- Climb high, sleep low
- Drugs
  - acetazolamide (Diamox)
    - diuretic, increases HCO_3^- excretion
  - dexamethasone
    - synthetic glucocorticoid (anti-inflammatory)
- High Carbohydrate diet (>70% cal.)

Hillary and Norgay



1953, Edmund Hillary and Tenzing Norgay