Pulmonary Problems at High Altitude

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I have nothing to disclose

Objectives

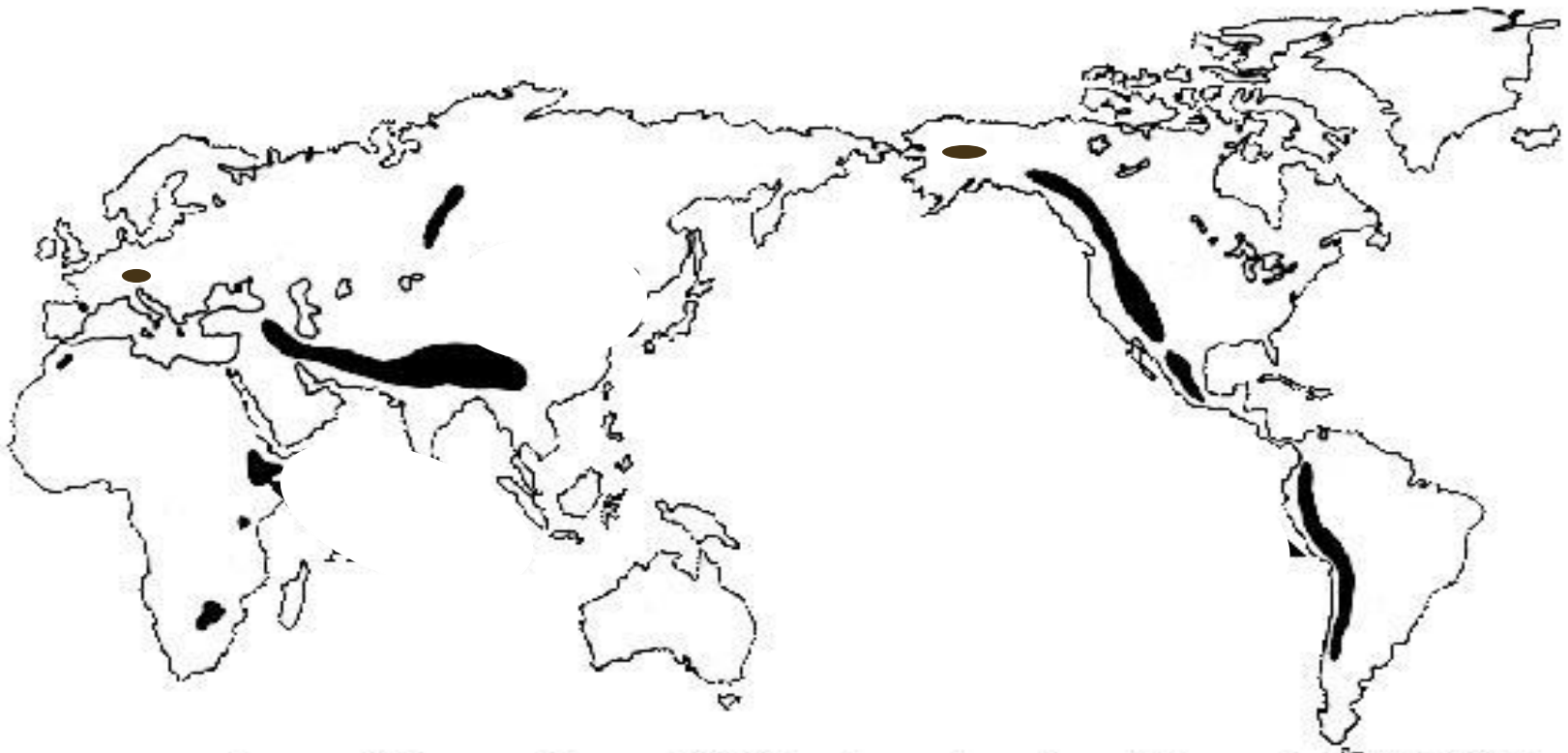
- To review the basic physiological changes that occur at high terrestrial altitude
- To describe the presentation and management of high altitude illnesses
- To discuss the exacerbation of sea level illnesses at high terrestrial altitude

Definitions

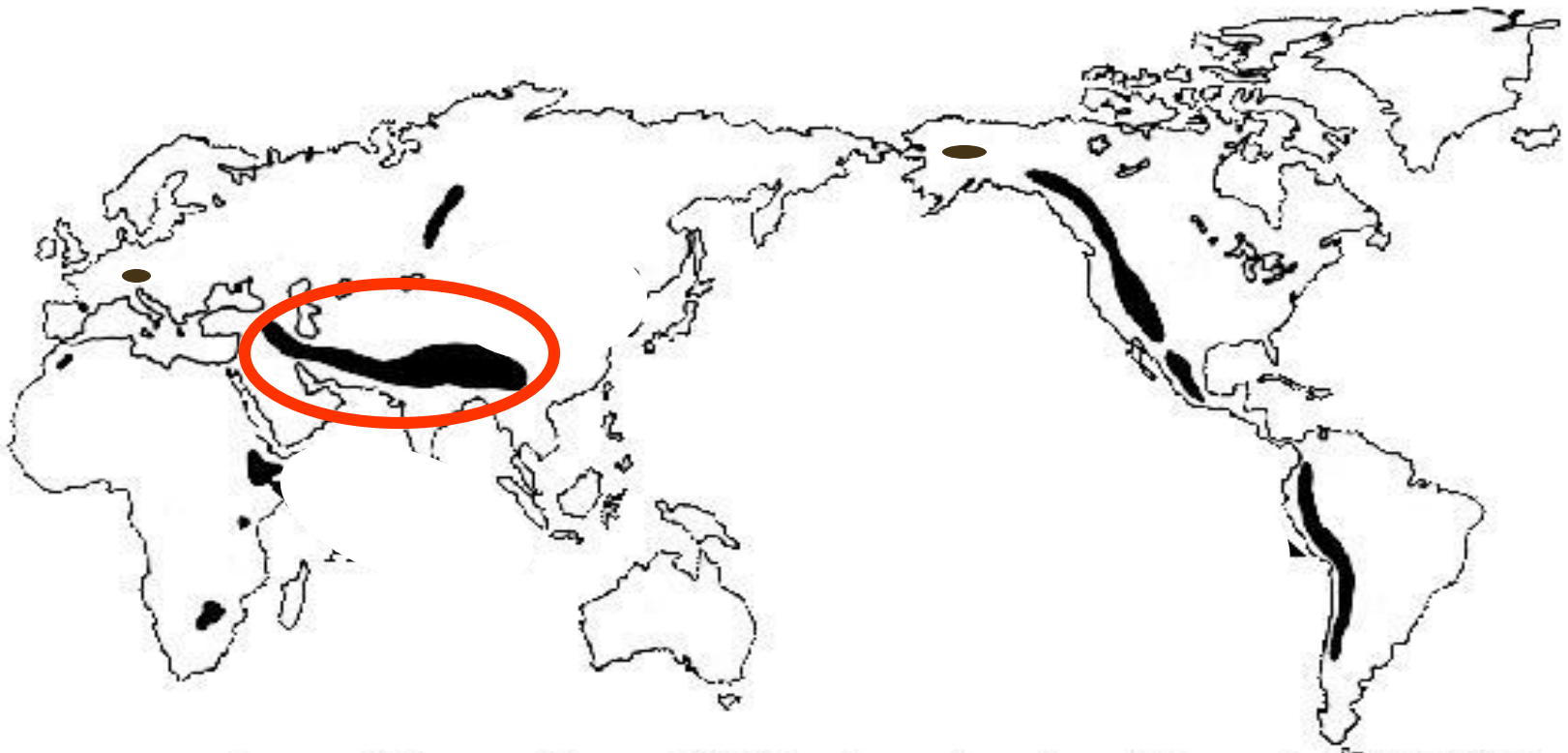
- Moderate Altitude: 5,000 - 8000 ft
- High Altitude: 8,000 – 14,000 ft
- Very High Altitude: 14,000 – 18,000 ft
- Extreme Altitude: 18,000 – 29028 ft

High Altitude Illnesses

- Serious Illnesses
  - High Altitude Pulmonary Edema
  - High Altitude Cerebral Edema
- Disabling Illnesses
  - Acute Mountain Sickness
  - Chronic Mountain Sickness
- Exacerbation of Sea Level Illnesses
  - COPD
  - Restrictive or interstitial lung disease
  - Pulmonary Hypertension

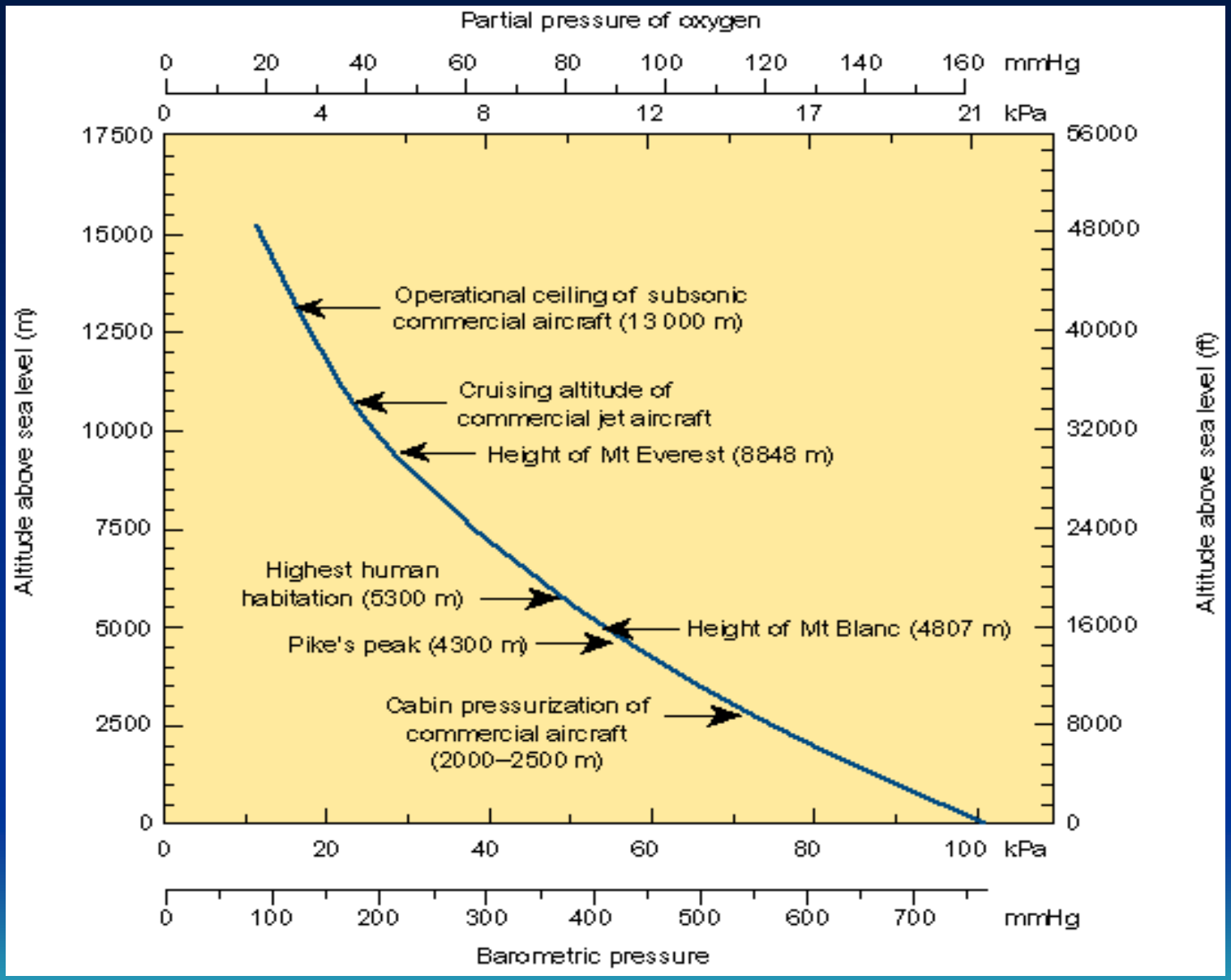


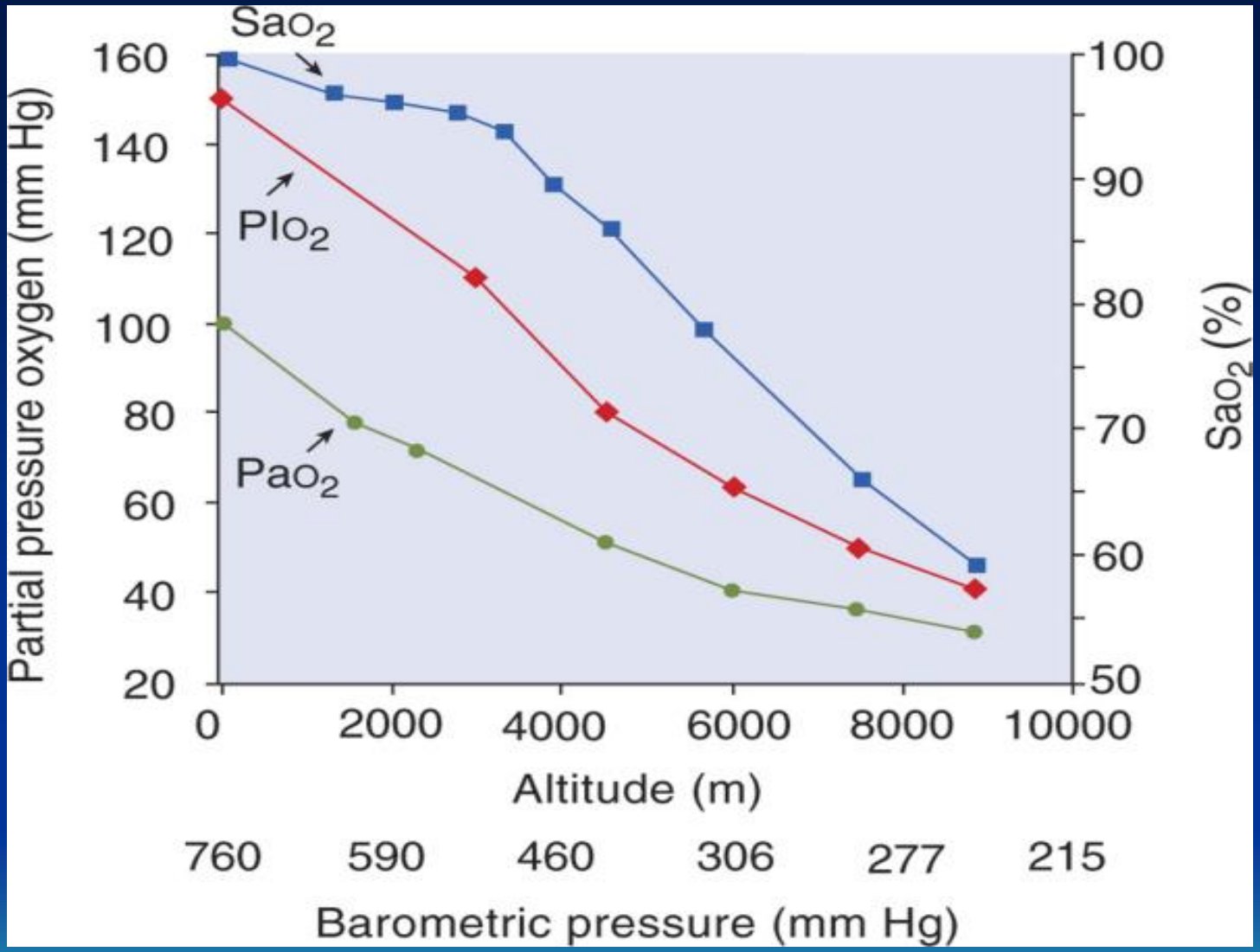
Areas of the world over 3,000 meters elevation (Frisancho 1993:224)



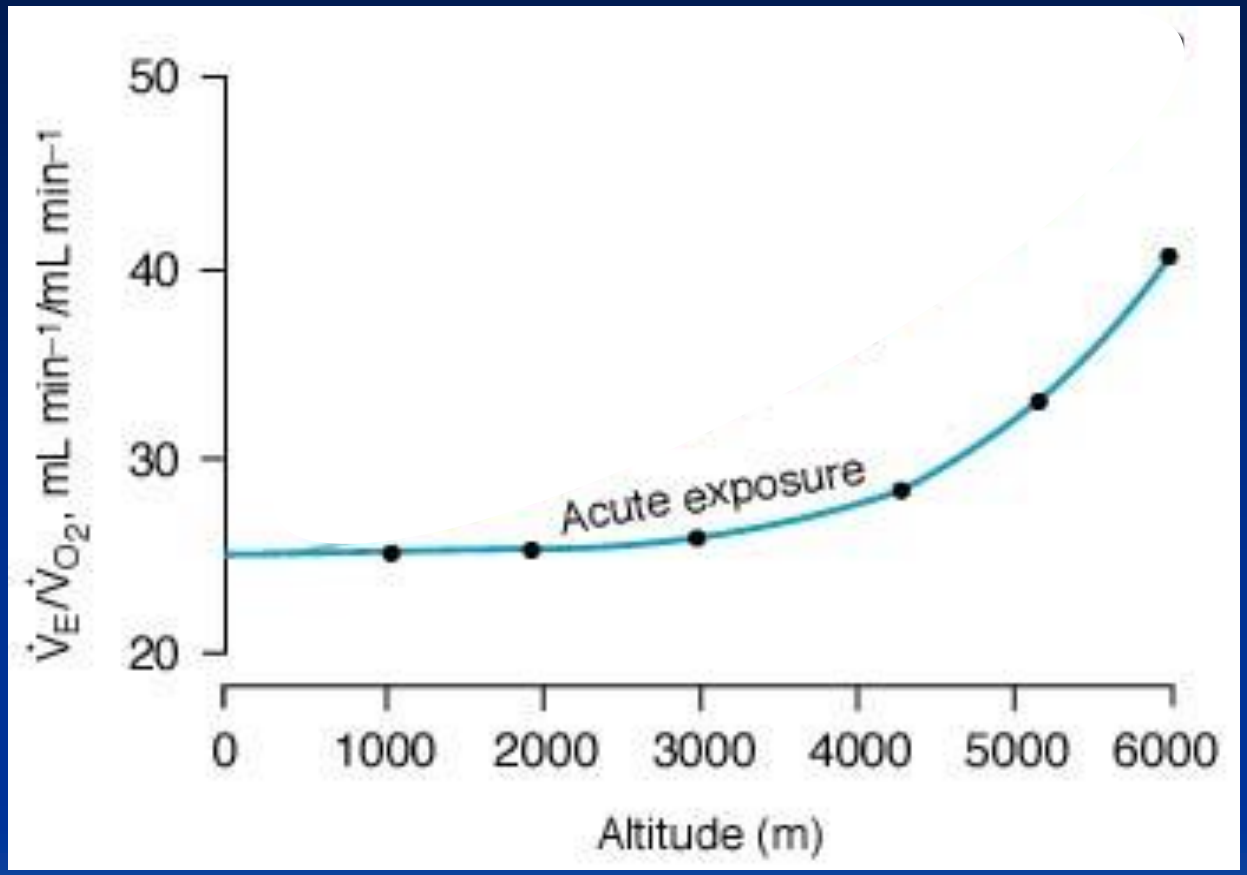
Areas of the world over 3,000 meters elevation (Frisancho 1993:224)

Basic Physiological Changes at High Altitude

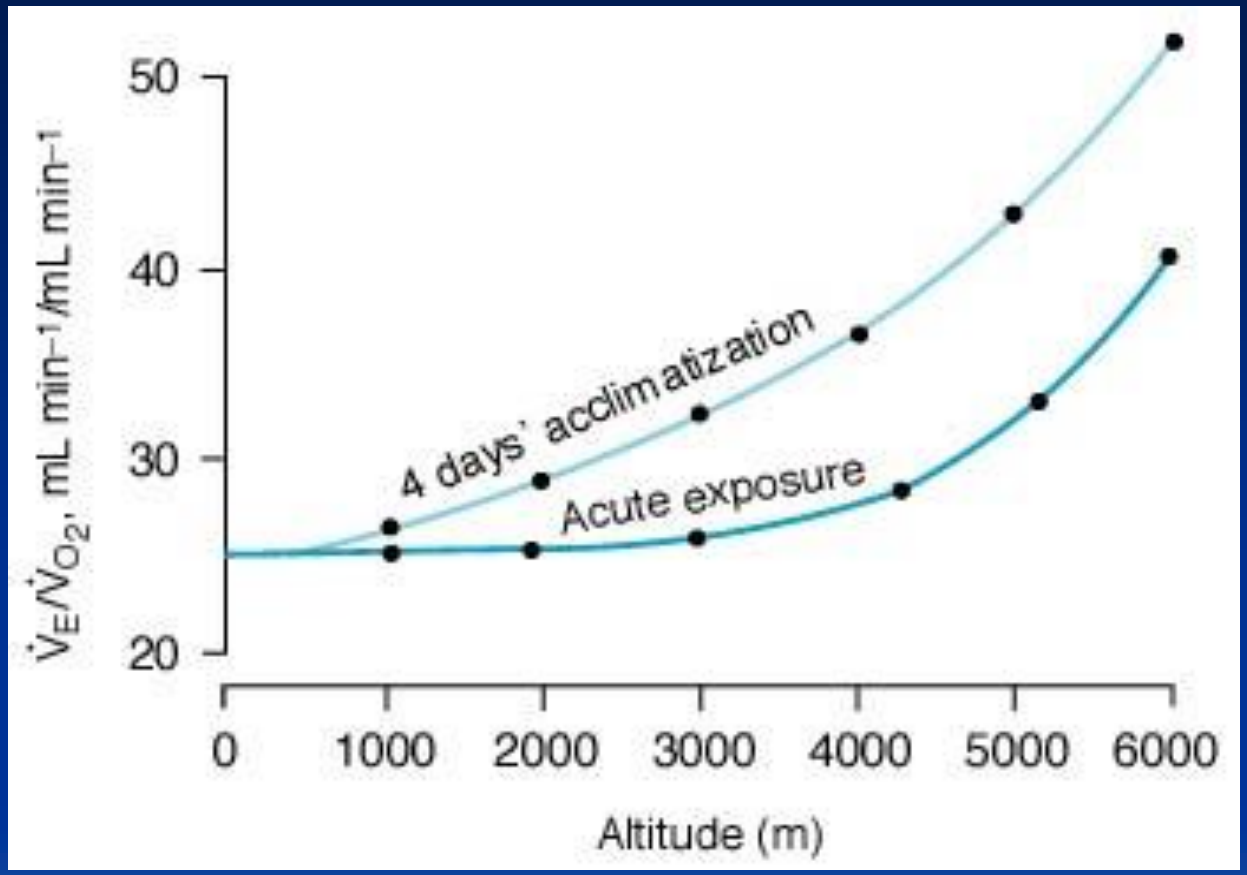

Partial pressure of oxygen
0 20 40 60 80 100 120 140 160 mmHg
0 4 8 12 17 21 kPa
Altitude above sea level (m)
17500
15000
12500
10000
7500
5000
2500
0
Altitude above sea level (ft)
56000
48000
40000
32000
24000
16000
8000
0
Operational ceiling of subsonic commercial aircraft (13 000 m)
Cruising altitude of commercial jet aircraft
Height of Mt Everest (8848 m)
Highest human habitation (5300 m)
Pike's peak (4300 m)
Height of Mt Blanc (4807 m)
Cabin pressurization of commercial aircraft (2000–2500 m)
0 20 40 60 80 100 kPa
0 100 200 300 400 500 600 700 mmHg
Barometric pressure



Sutton JR et al: J Appl Physiol 64:1309, 1988.



Lenfant C, Sullivan K. Adaptation to high altitude. *N Engl J Med*. 1971;284:1303.



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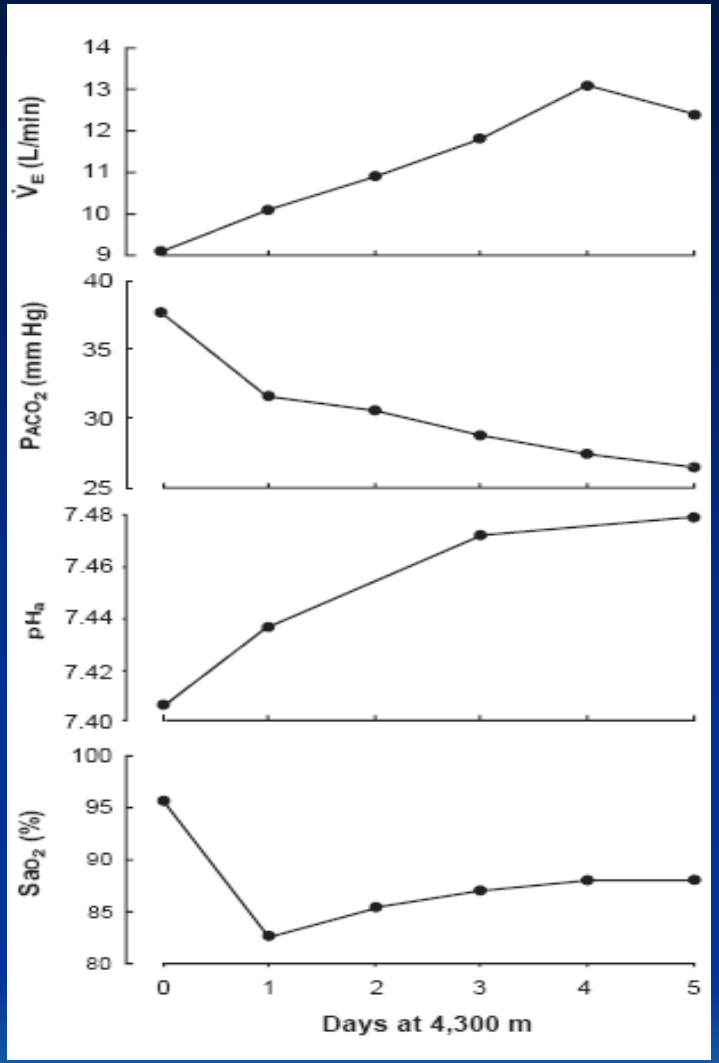
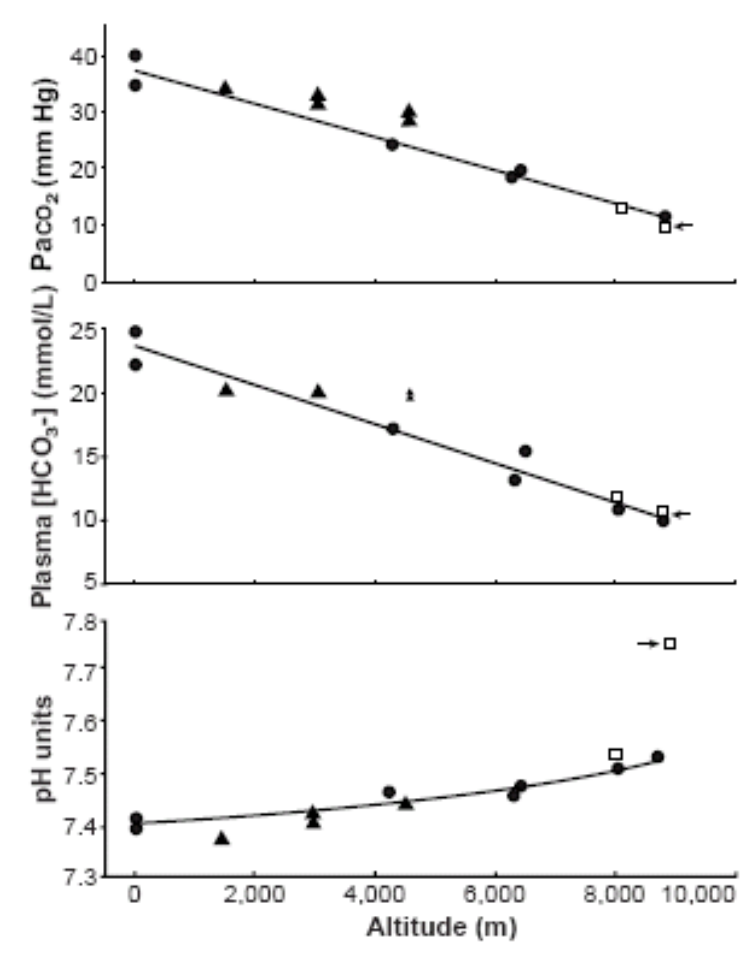
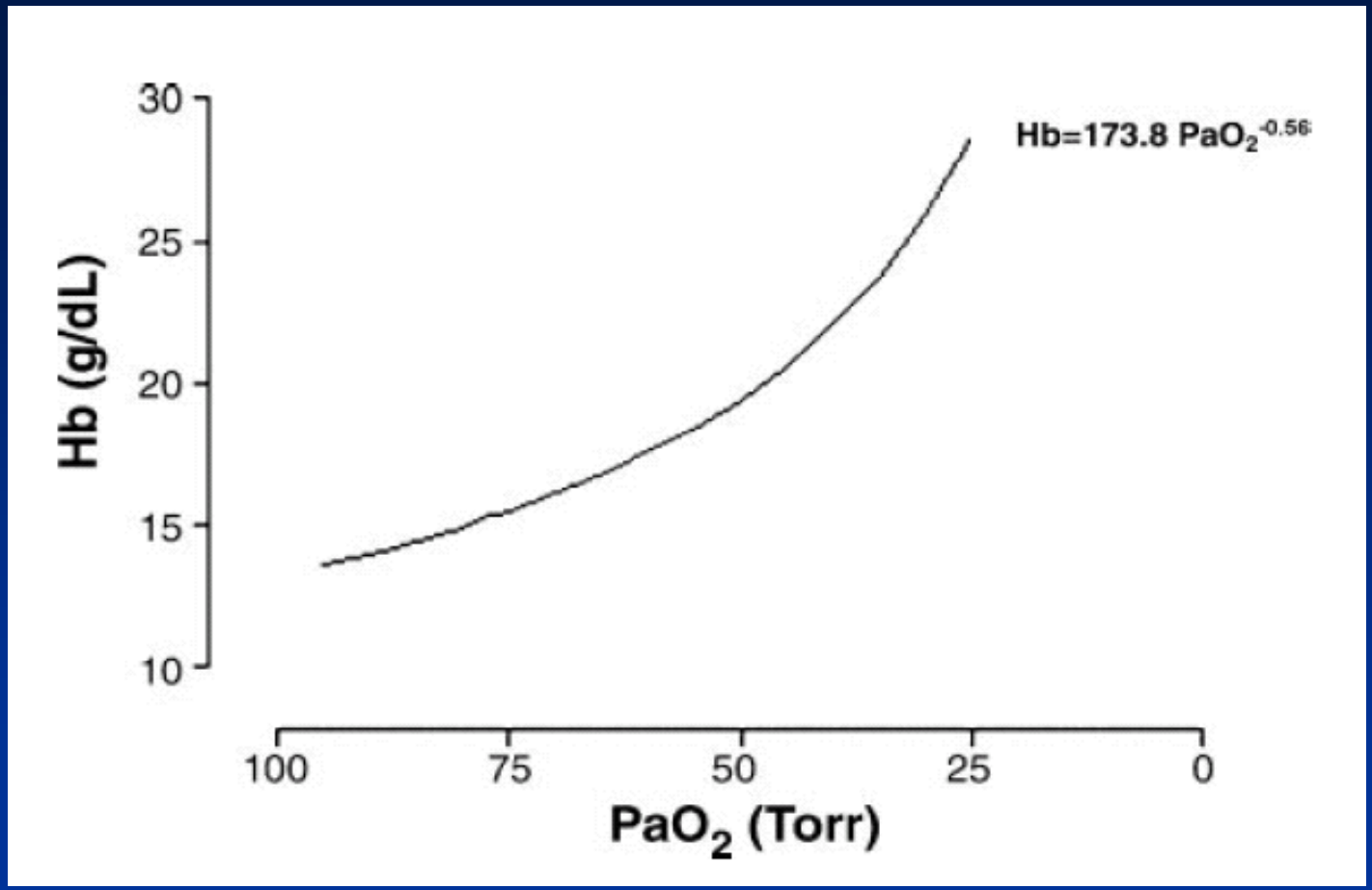


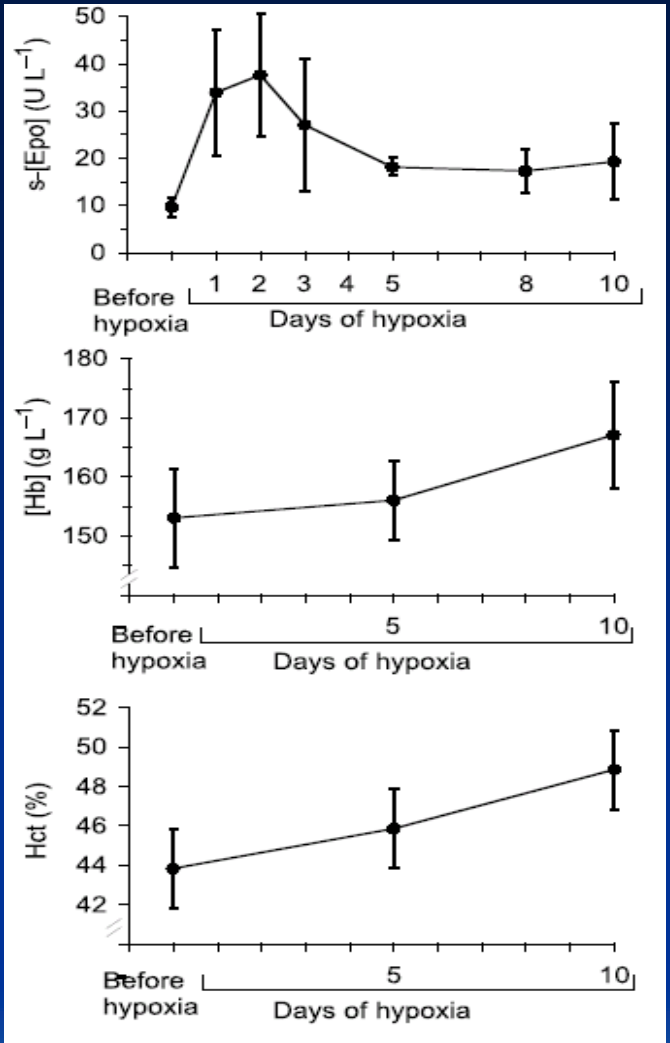
Huang SY, Alexander JK, Grover RF, et al. Hypocapnia and sustained hypoxia blunt ventilation on arrival at high altitude. *J Appl Physiol*. 1984;56:603.



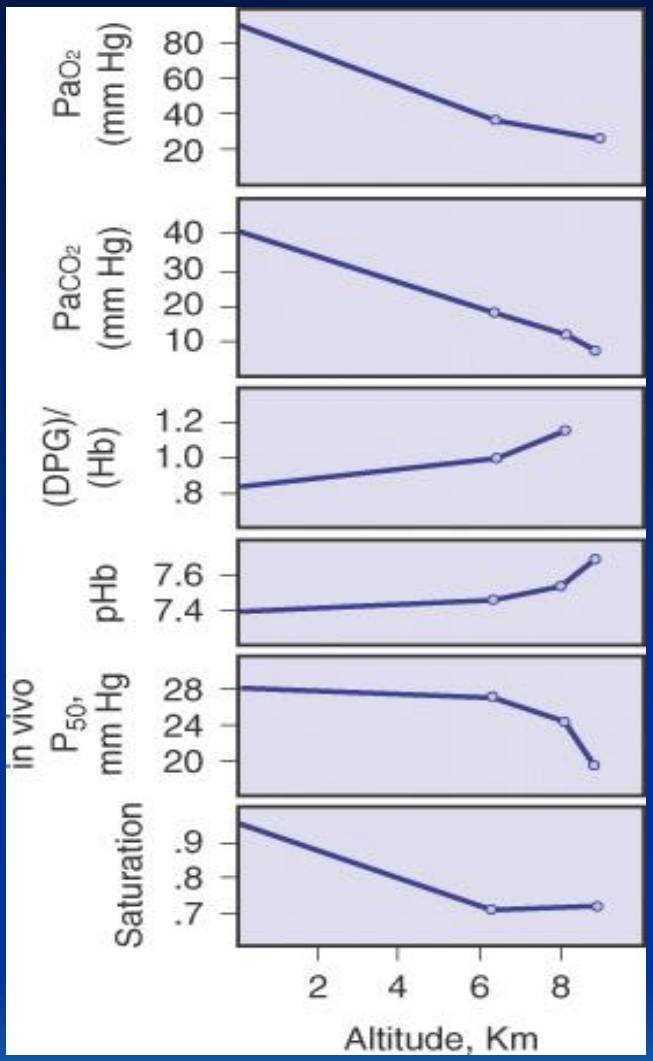
Sutton JR, Reeves JT, Wagner PD, et al. Operation Everest II: Oxygen transport during exercise at extreme simulated altitude. *J Appl Physiol.* 1988;64:1309–1321.



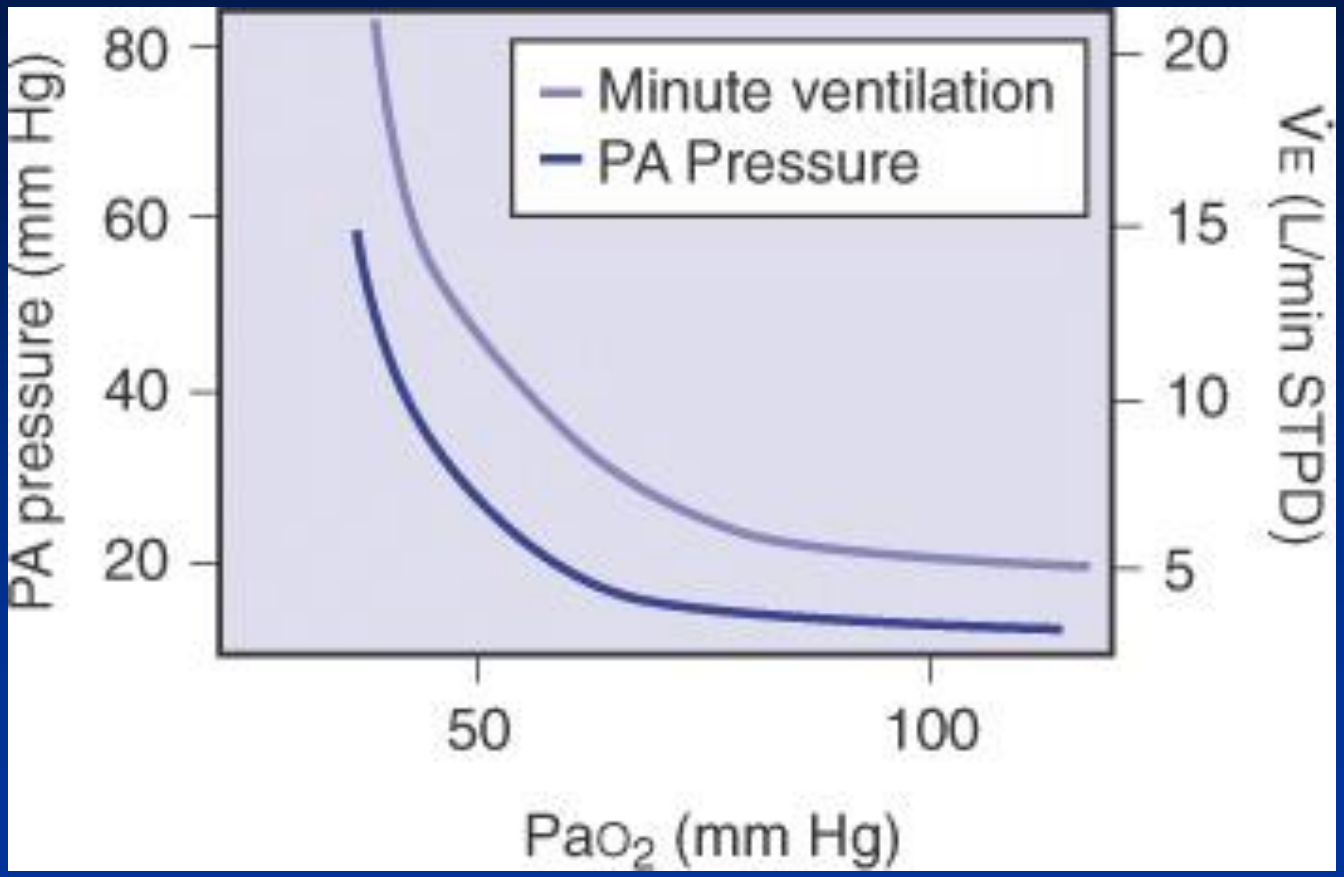
Villafuerte FC, Cardenas R, Monge CC. Optimal hemoglobin concentration at high altitude: A theoretical approach for Andean men at rest. *J Appl Physiol* 96: 1581–1588, 2004.



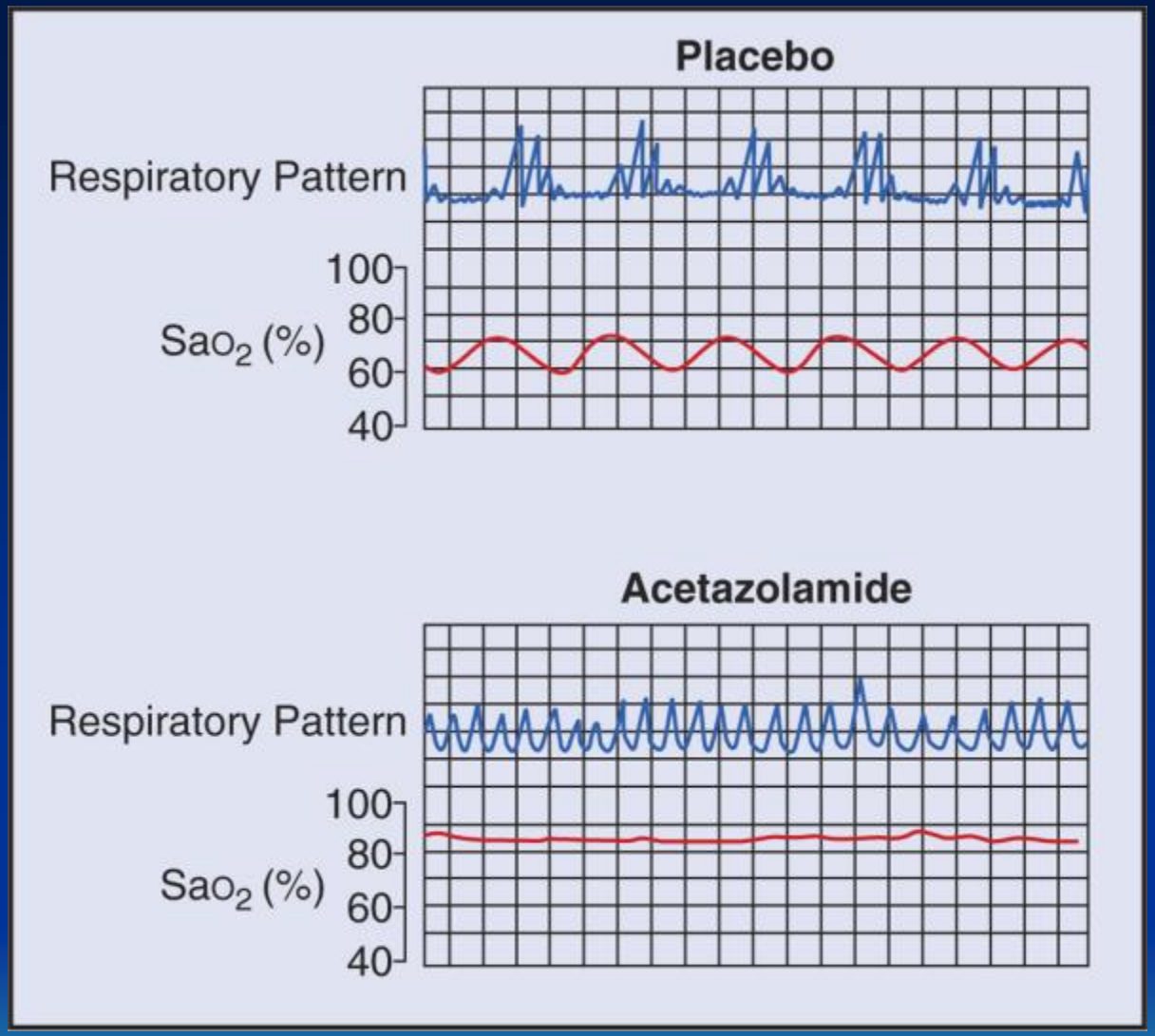
Berglund B, Genser M, Ornhagen H, et al. Erythropoietin concentrations during 10 days of normobaric hypoxia under controlled environmental circumstances. Acta Physiol Scand 2002, 174, 225-229.



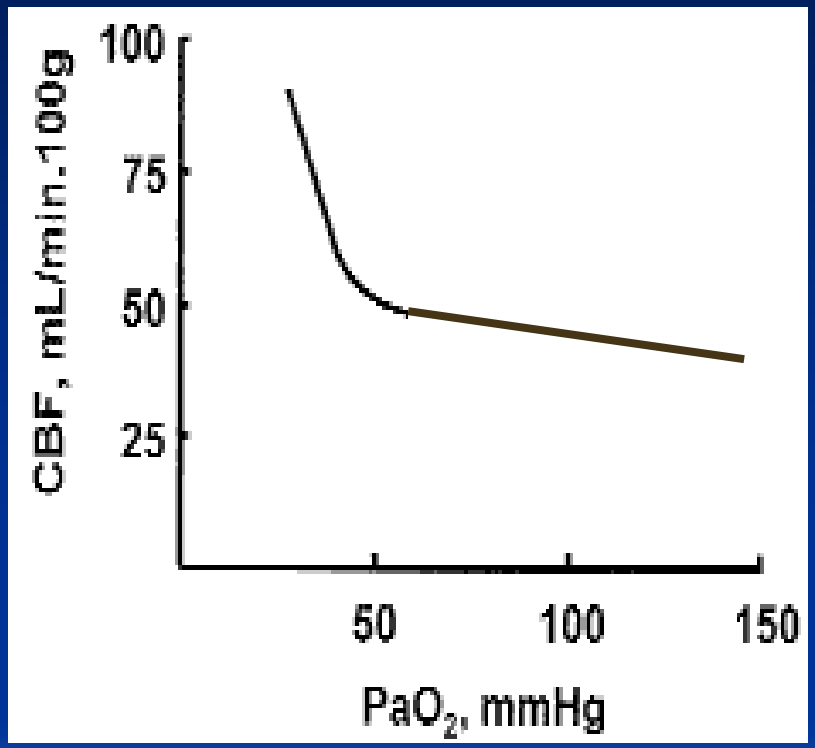
Winslow RM, Samaja M, West JB: Red cell function at extreme altitude on Mount Everest. J Appl Physiol 56:109–116, 1984

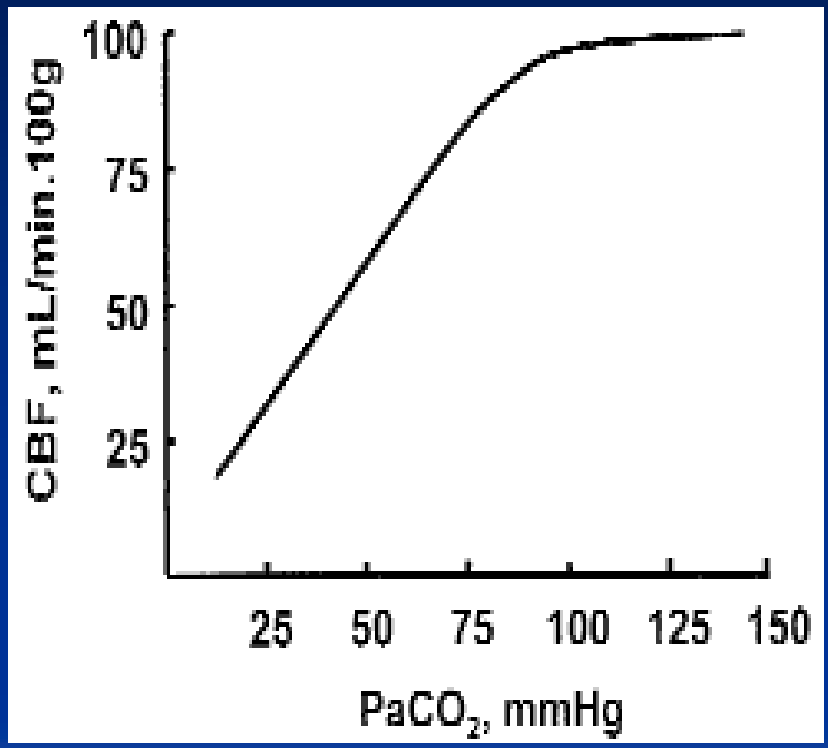


Reeves JT, Wagner, WW Jr, McMurtry F, et al: Physiological effects of high altitude on the pulmonary circulation. *In* Robertshaw D [ed]: International Review of Physiology, Environmental Physiology III. Baltimore: University Park Press, 1979, pp 289-310.



Hackett PH et al: Am Rev Respir Dis 135:896, 1987.


CBF, mL/min.100g
100
75
50
25
50
100
150
PaO2, mmHg


CBF, mL/min.100g
100
75
50
25
25
50
75
100
125
150
PaCO2, mmHg

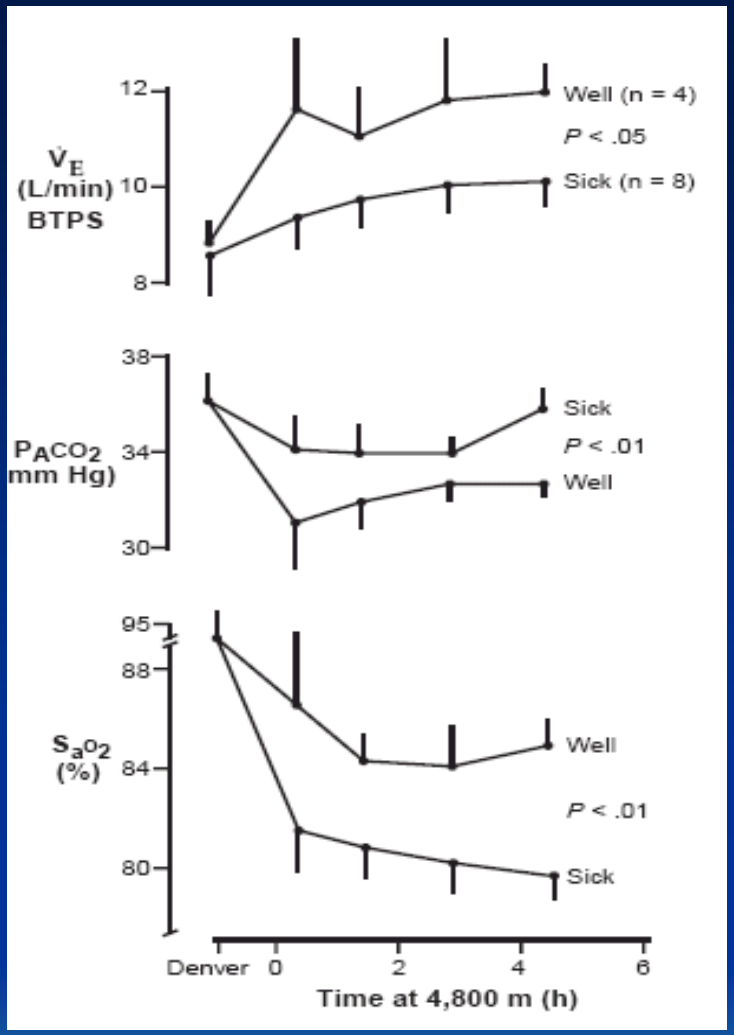
Acute Mountain Sickness

Acute Mountain Sickness
Symptoms

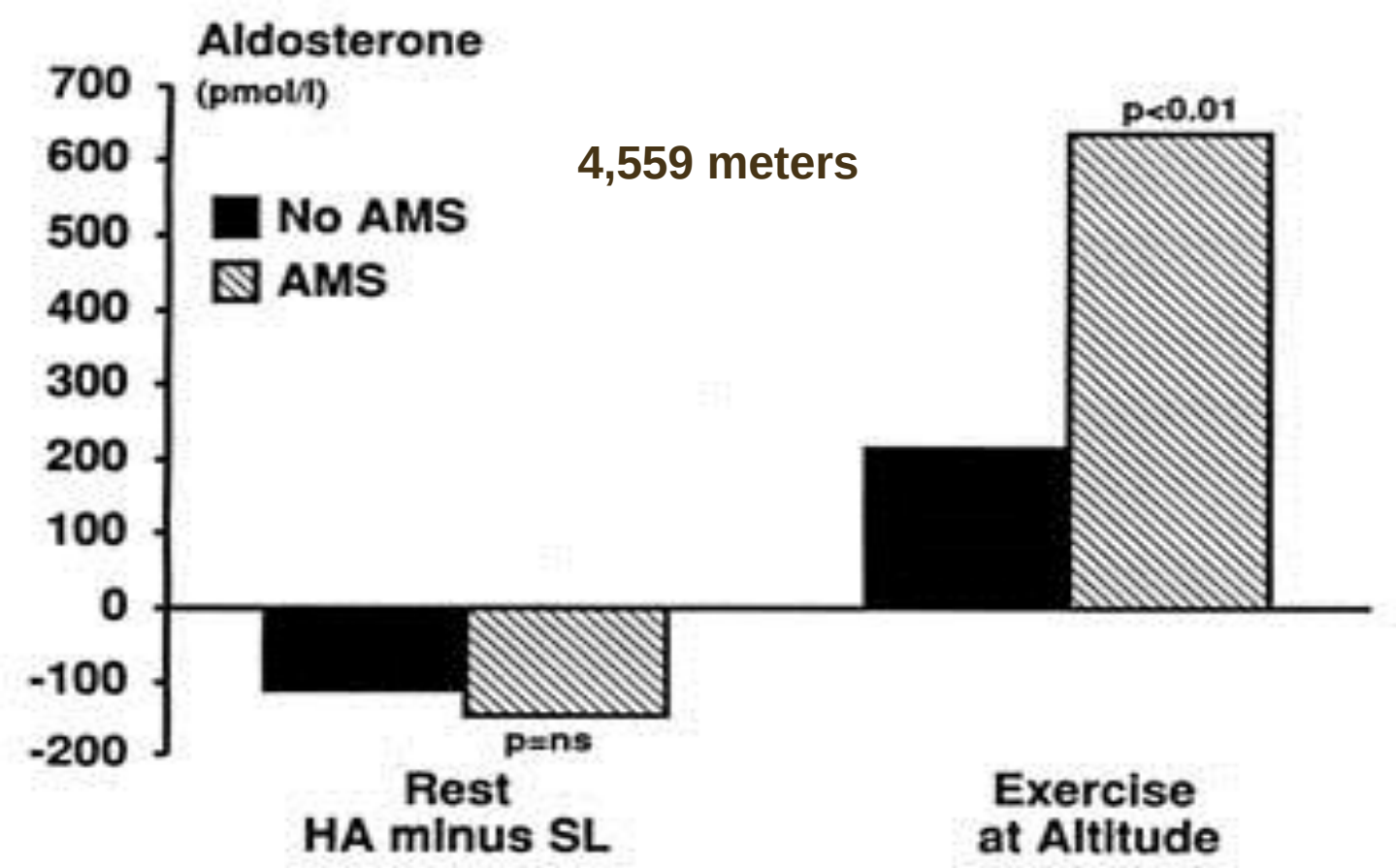
- Headache – Always Present
- Plus one or more of the following:
  - Nausea
  - Vomiting
  - Fatigue or weakness
  - Dizziness or lightheadedness
  - Difficulty Sleeping

Acute Mountain Sickness
Epidemiology

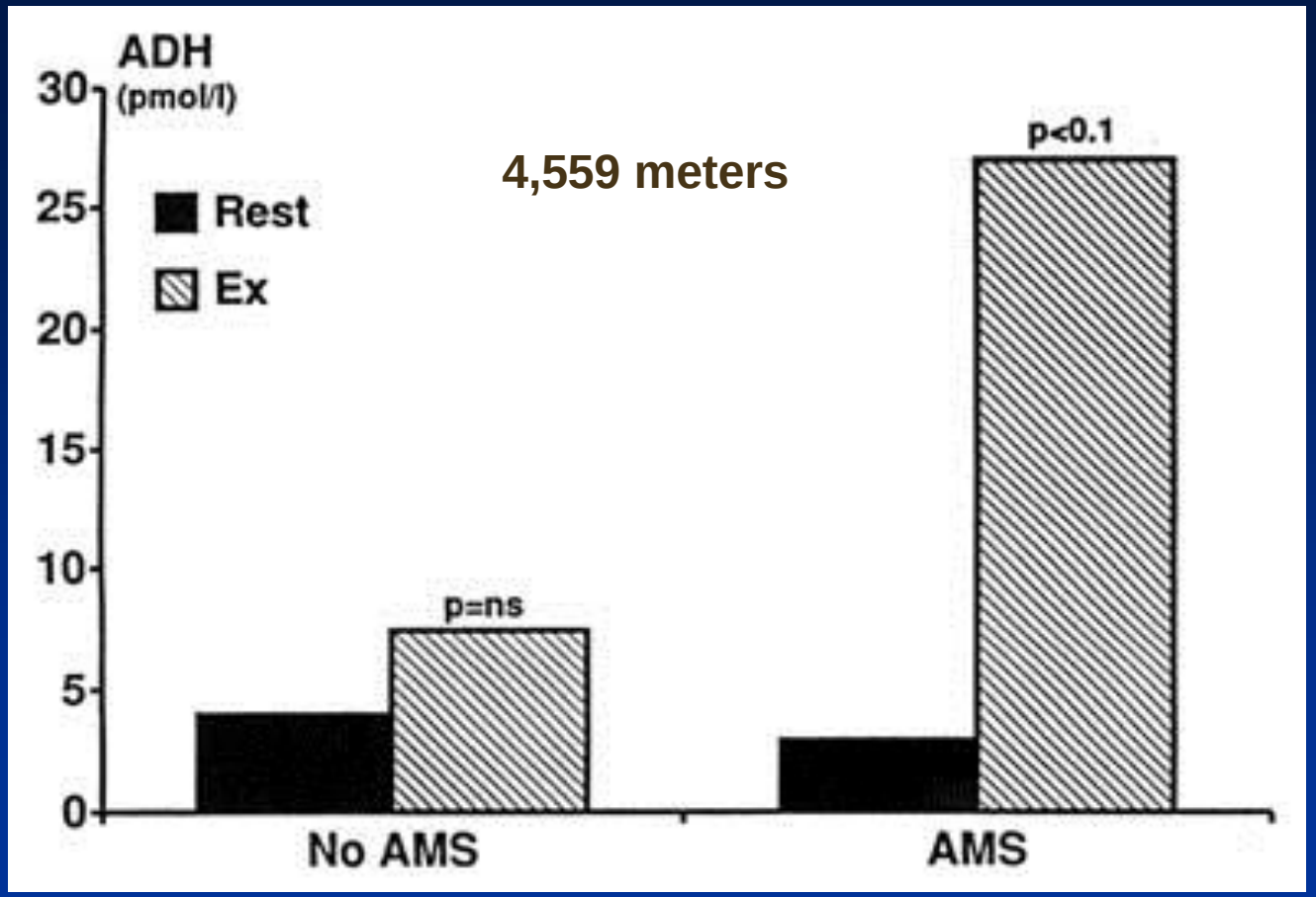
- Typically occurs at altitudes > 8,000 ft
- Affects 50-60% of individuals at altitudes > 10,000 ft
- Symptoms are more severe with rapid ascent and exercise
- Symptoms are most severe on the 2nd and 3rd days after acute ascent
- Symptoms typically resolve after 3 to 5 days, as one becomes aclimatized.



Moore LG, Harrison GL, McCullough RE, et al. Low acute hypoxic ventilatory response and hypoxic depression in acute altitude sickness. *J Appl Physiol.* 1986;60:1407–1412.



Bärtsch, P., M. Maggiorini, W. Schobersberger, S. Shaw, W. Rascher, J. Girard, P. Weidmann, and O. Oelz 1991a Enhanced exercise-induced rise of aldosterone and vasopressin preceding mountain sickness. J. Appl. Physiol. 71:136–143.



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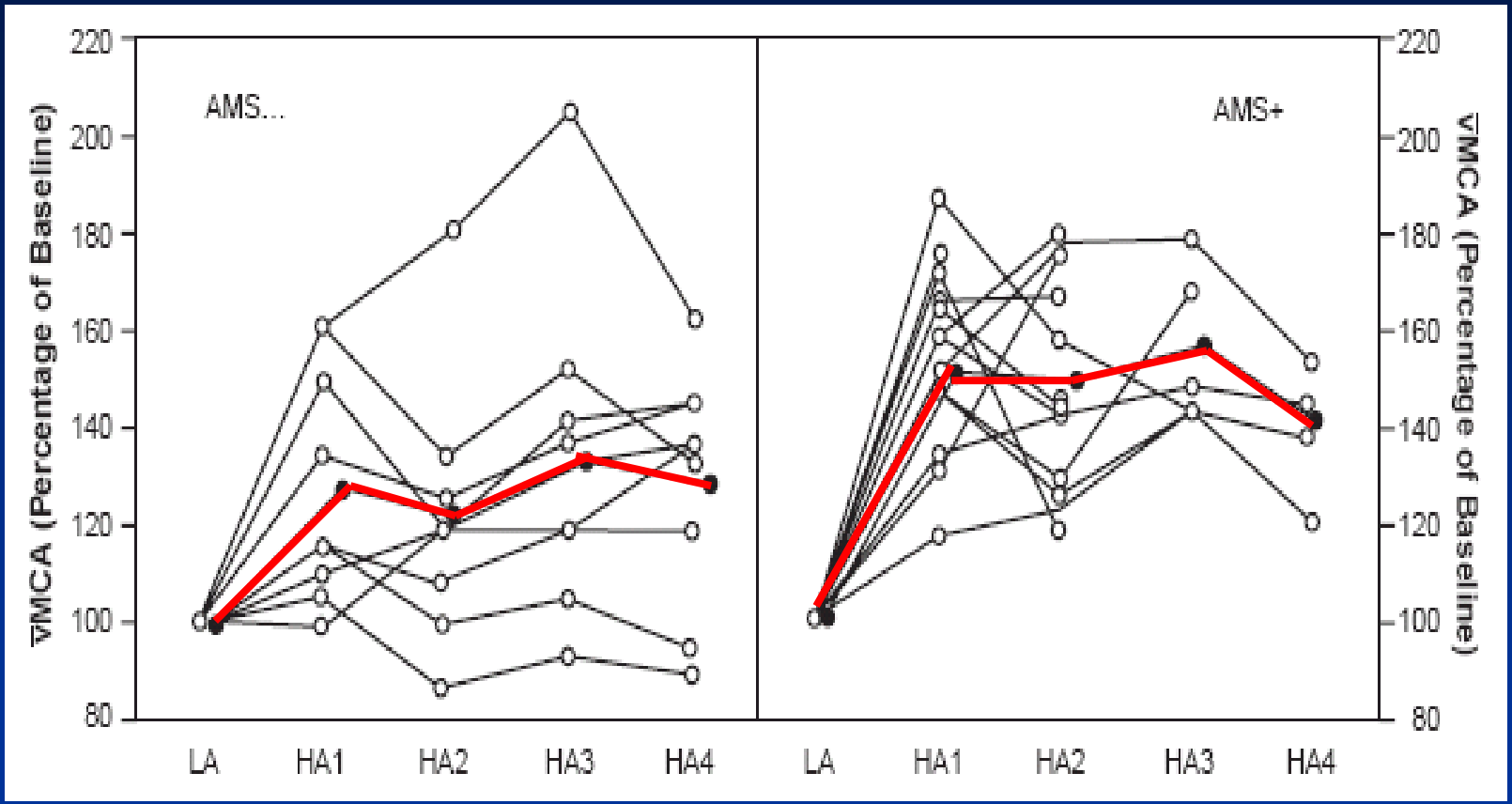
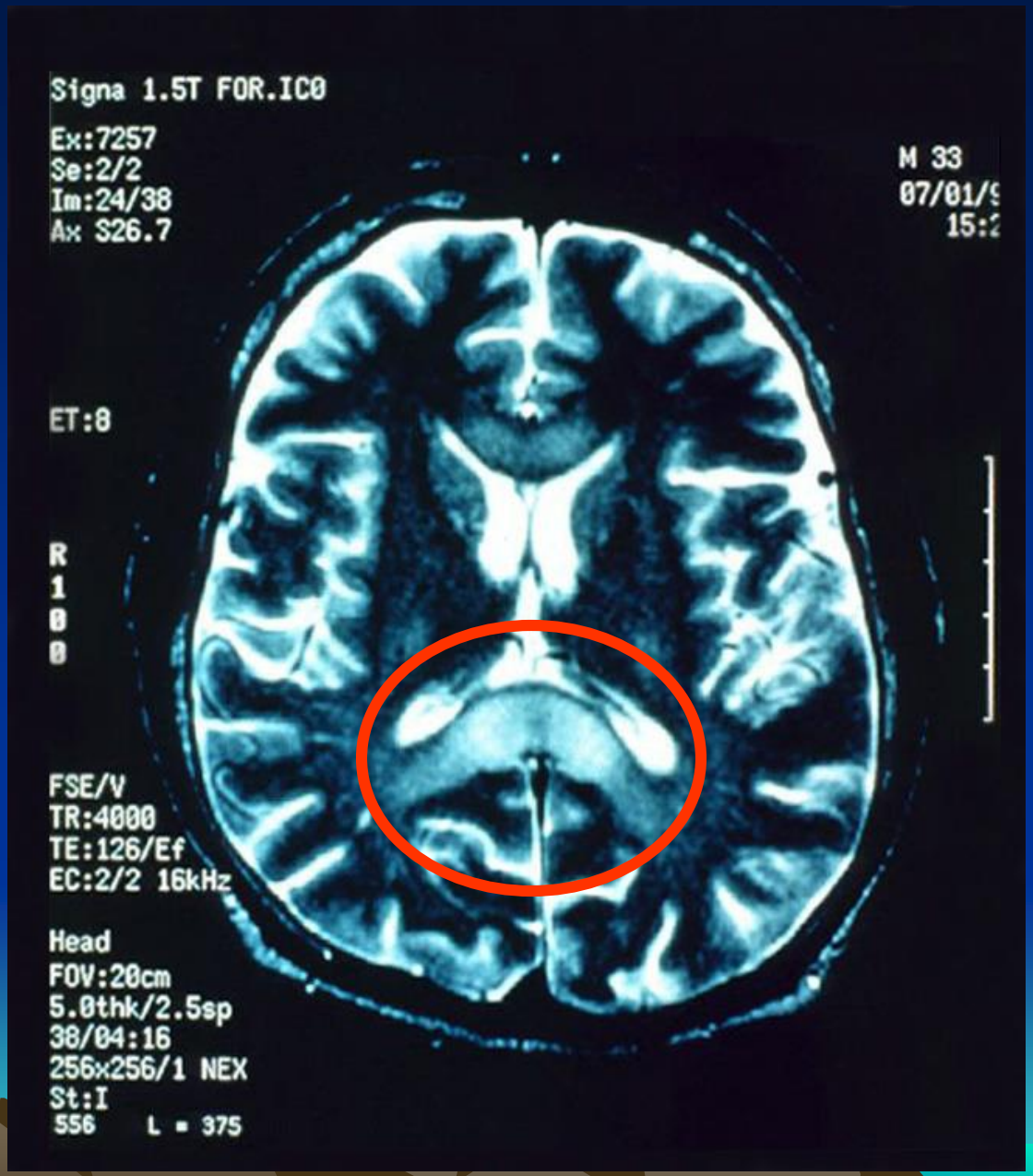
HA = 4.559 meters



Baumgartner RW, Bärtsch P, Maggiorini M, Waber U, Oelz O. Enhanced cerebral blood flow in acute mountain sickness. *Aviat Space Environ Med.* 1994;65:726–729.


Signa 1.5T FOR.IC0
Ex:7257
Se:2/2
Im:24/38
Ax S26.7
M 33
07/01/9
15:2
ET:8
R
1
0
0
FSE/V
TR:4000
TE:126/Ef
EC:2/2 16kHz
Head
FOV:20cm
5.0thk/2.5sp
38/04:16
256x256/1 NEX
St:I
556 L = 375

Acute Mountain Sickness
Physiological Profile

	NORMAL	AMS
V_E	+ +	+
P_aO_2	-	- -
P_aCO_2	- -	-
pH	+ +	+
Aldo -Exercise	+	+ +
ADH	+	+ +
ANP	+	+ +
Diffusion Capacity	++	+ / -
CBF	+	+ +
ARI	+ +	+

Acute Mountain Sickness
Prevention

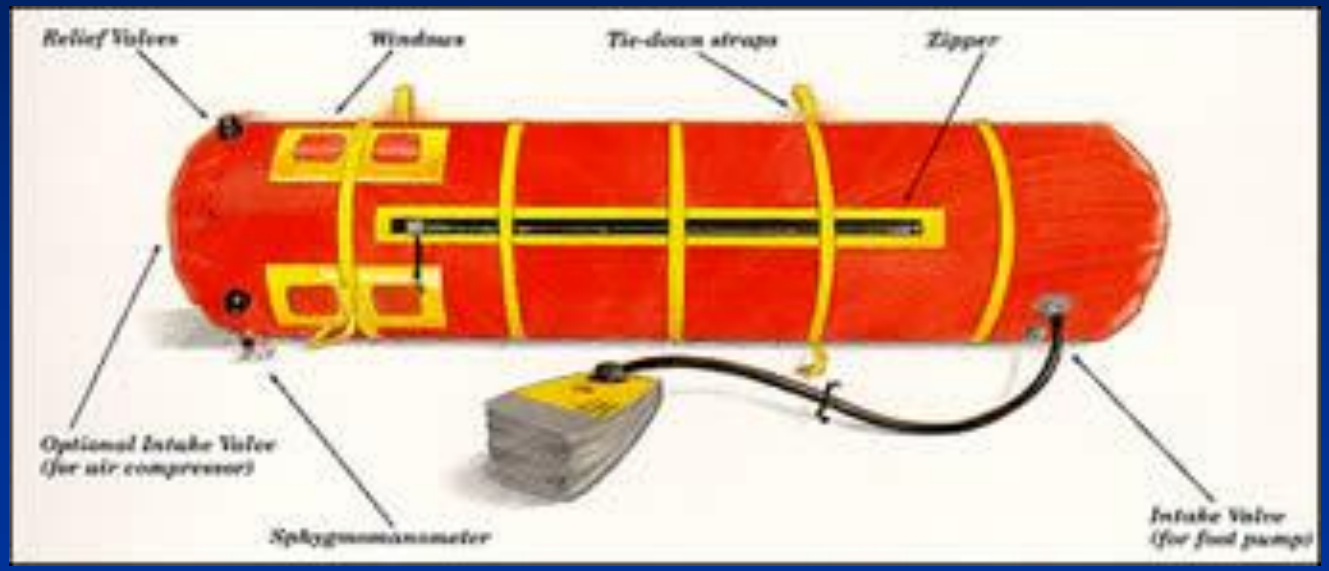
- Acclimatization at intermediate altitude is the most effective method:
  - For ascents between 8,000 and 14,000 ft, spend 2 to 4 days at 5,000 to 7000 ft
  - For ascents > 14,000 ft, spend an additional 2 to 4 days at 10,000 to 12,000 ft

Acute Mountain Sickness
Prevention

- Chemoprophylaxis
  - Acetazolamide
    - 500 mg of long acting preparation QD
  - Dexamethasone
    - 4 mg, Q6H
  - Acetazolamide plus dexamethasone
    - 500 mg of AZ QD + 4 mg DEX Q12H
    - 500 mg of AZ QD + 2 mg of DEX Q6H

Acute Mountain Sickness
Treatment

- Descent to lower altitude !
- Continuous O_2 adminstration
- Dexamethasone
  - 4 mg Q6H
- Gamow bag


Relief Valves
Windsock
Tie-down straps
Zipper
Optional Intake Valve
(for air compressor)
Sphygmomanometer
Intake Valve
(for foot pump)

High Altitude Cerebral Edema
Symptoms

- Extreme form of AMS
- Severe headache
- Ataxia – early warning sign
- Confusion and impaired thinking
- Extreme lethargy
- Paresthesias
- Seizures
- Stupor and coma

High Altitude Cerebral Edema
Treatment

- Descent to lower altitude ASAP !
- Continuous O_2 adminstration
- Dexamethasone
  - 8 mg STAT then 4 mg Q6H (PO or IV)
- If conscious – Gamow bag
- If unconscious or stuporous - Intubation and hyperventilation

High Altitude Pulmonary Edema

High Altitude Pulmonary Edema
Symptoms

- Dyspnea
- Chest heaviness
- Non-productive cough
- Watery and frothy sputum
- Hemoptysis (in 20% of cases)
- Obtundation

Precedes death by 6 to 12 hours

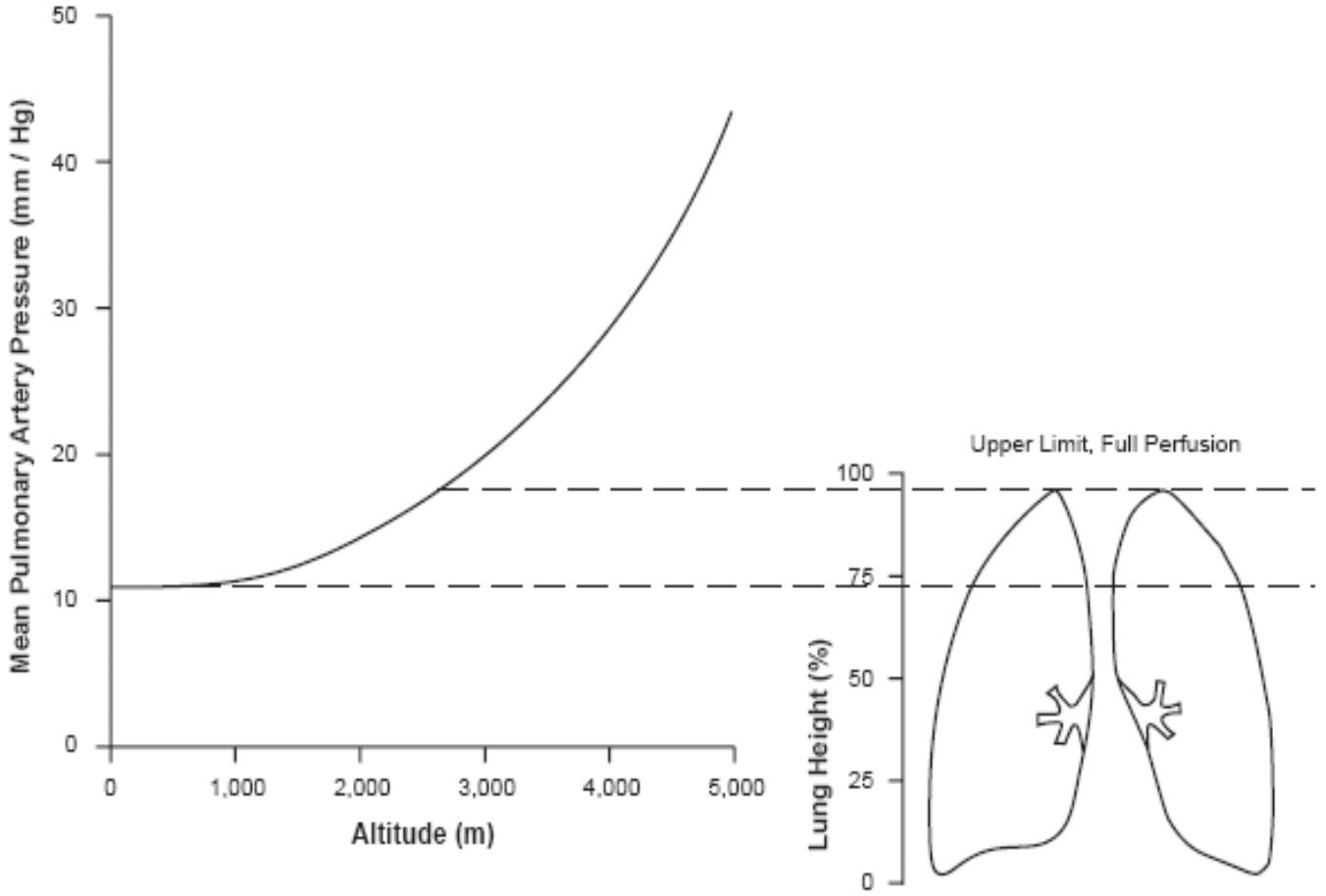
High Altitude Pulmonary Edema
Clinical Signs

- Hyperpnea
- Rales
- Tachycardia
- Cyanosis
- Hypotension

High Altitude Pulmonary Edema
Epidemiology

- Typically occurs at altitudes > 10,000 ft
- Affects 5% of individuals who make an acute ascent to high altitude
- 12% have had previous episodes
- Typically occurs 3 to 5 days after acute ascent
- Exercise and cold are contributing factors
- Mortality rate is 27%

Jerusalem, Aug. 23, 2001. Amram J. "Ami" Cohen, a prominent heart surgeon who built a program that brought hundreds of children from developing countries to Israel for live saving cardiac operations died on August 16 while climbing Mount Kilimanjaro in Tanzania. He was 47.



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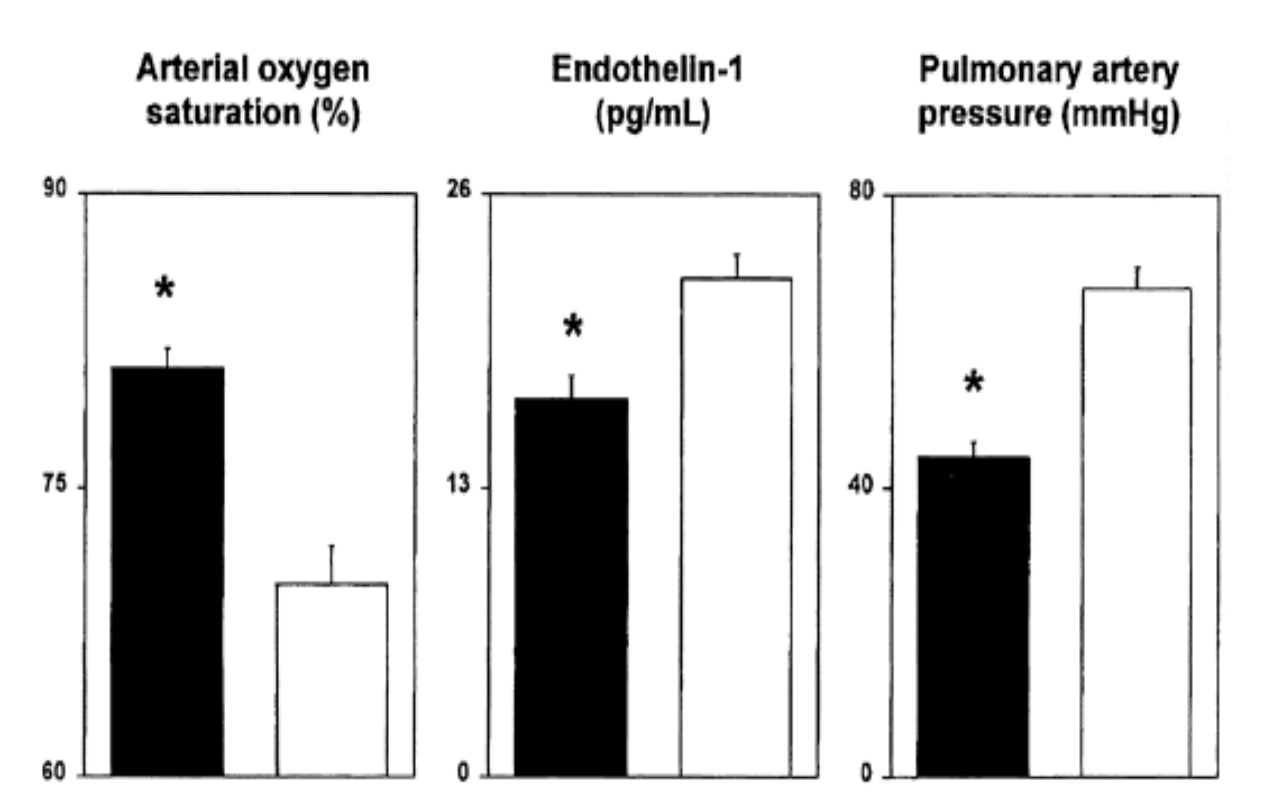
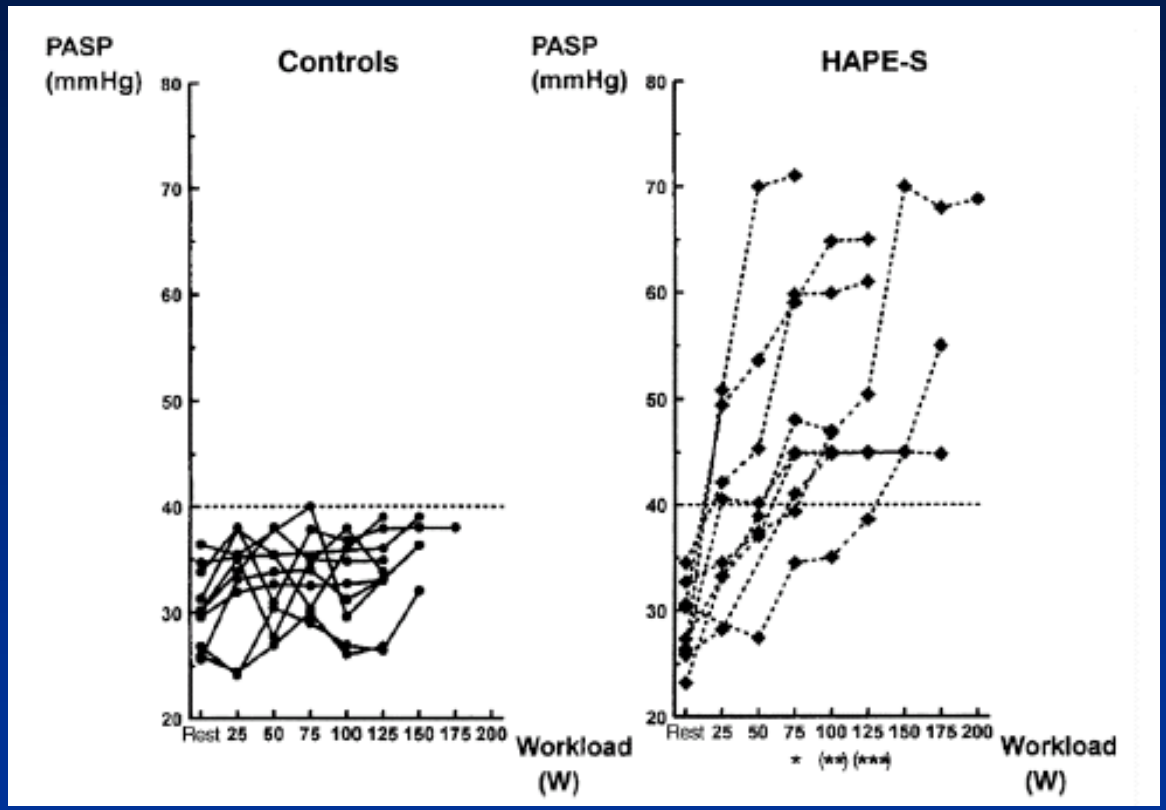


Sartori C., Vollenweider L., Loffler B.-M., Delabays A., Nicod P., Bartsch P., and Scherrer U. (1999b). Exaggerated endothelin release in high-altitude pulmonary edema. Circulation 99:2665–2668.



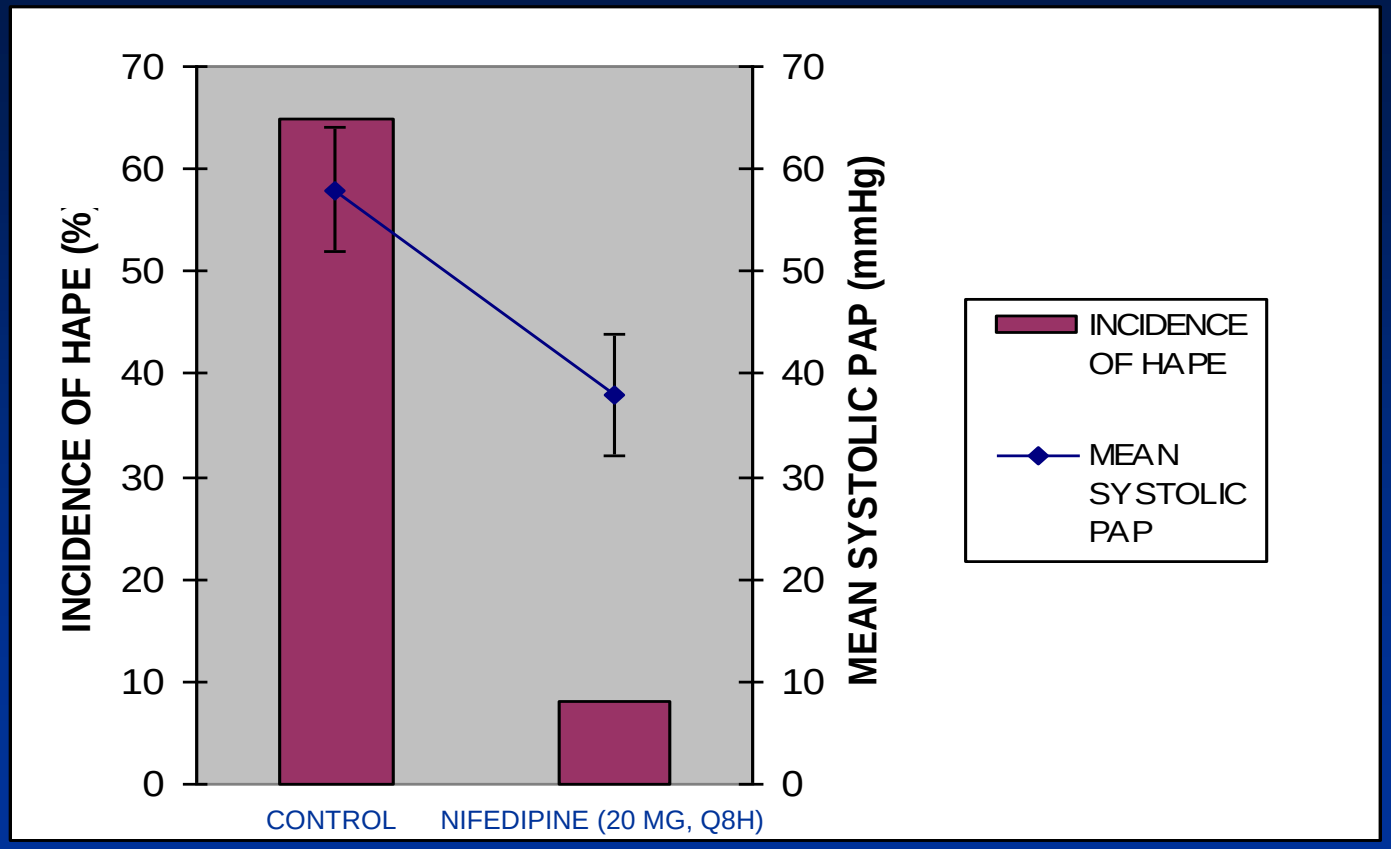
Grunig E., Mereles D., Hildebrandt W., Swenson E.R., Kubler W., Kuecherer H., and Bartsch P. (2000). Stress Doppler echocardiography for identification of susceptibility to high altitude pulmonary edema. J. Am. Coll.Cardiol. 35:980–987.

High Altitude Pulmonary Edema
Physiological Profile

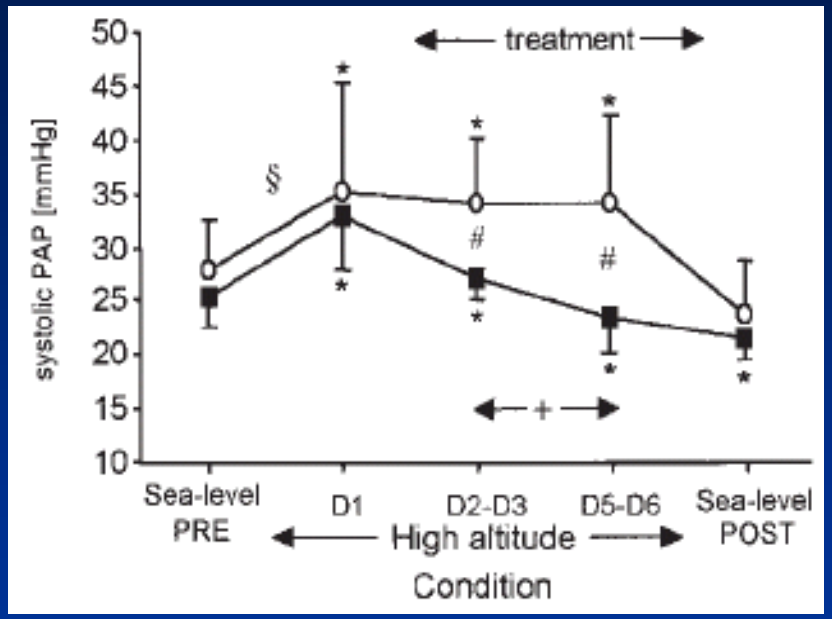
	NORMAL	HAPE
PA Blood Flow	+	+ +
PA Pressure	+	+ +
PC Pressure	+	+ +
Endothelial Breaks	-	+
Exhaled NO	+ +	+
Adrenergic Stimulation	+	+ +
V_E	+ +	+

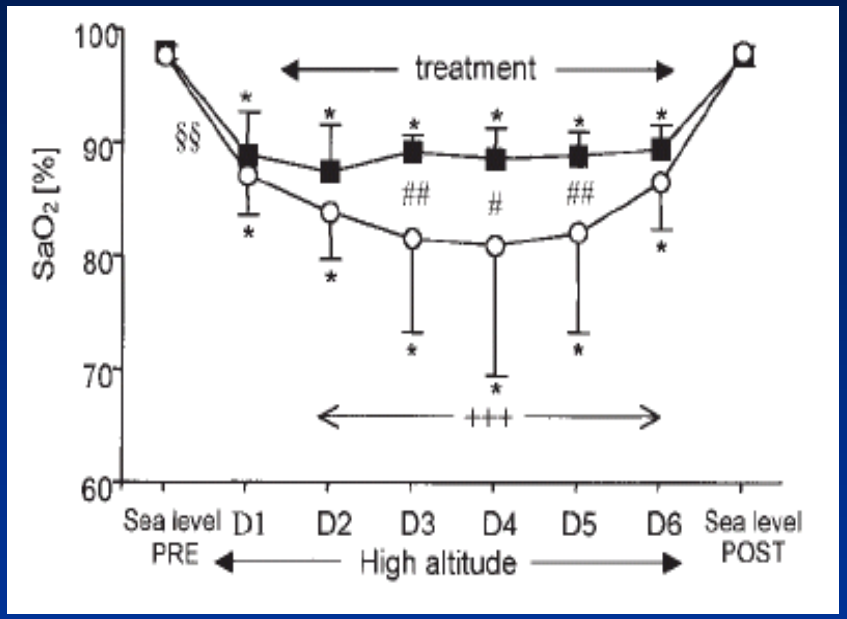
High Altitude Pulmonary Edema
Prevention

- Acclimatize at intermediate altitudes
- Ascend using supplemental oxygen
- Stay warm
- Chemoprophylaxis



Bartsch P, Maggiorini M, Ritter M, et al. Prevention of high-altitude pulmonary edema by nifedipine. New Engl J Med 1991; 325:1284-1289





- **Sildenafil 40 mg Q8H o Placebo**

Richalet JP, Gratadour P, Robach P, et al. Sildenafil inhibits altitude-induced hypoxemia and pulmonary hypertension. Am J Respir Crit Care Med 2005; 171: 275–281.

High Altitude Pulmonary Edema
Prevention

- Nifedipine – 20 mg, Q8H, for 5 days
- Sildenafil – 40 mg, Q8H, for 5 days

High Altitude Pulmonary Edema
Treatment

- Descend to lower altitude !
- Oxygen
- Gamow bag
- Nifedipine – 10 mg SL + 20 mg Q6H

High Altitude Pulmonary Edema
Treatment

- Acetazolamide is not effective
- Furosemide is not effective
- Morphine is not effective

Sea-Level Problems at High Altitude

COPD

Predictors of Poor Performance at Altitude

- Dyspnea on exertion
- P_aO_2 < 70 mm Hg at or near sea-level
- P_aO_2 < 50 mmHg at altitude
- MVV < 40 L/min
- CO_2 retention

COPD

Recommendations

- If **any one** of the predictors of poor performance at altitude are present:
  - **Do not** ascend to high altitude (> 8,000 feet)
  - Supplemental O_2 for ascent to moderate altitudes (5,000 to 8,000 feet)
    - 2 L/min if not on baseline supplemental O_2
    - If on baseline supplemental O_2 – increase flow rate by 33%

COPD

Prediction of P_aO_2 at Altitude

$$P_aO_2 \text{ Alt} = 0.453 \times P_aO_2 \text{ Ground (mm Hg)} + 0.386 \times (\text{FEV1 \% predicted}) + 2.44$$

P_aO_2 Alt is the predicted in-flight oxygen tension at aircraft cabin altitude in mm Hg

P_aO_2 Ground is the baseline arterial oxygen tension measured at ground altitude in mm Hg

FEV1 (% predicted) is the percentage of the predicted forced expiratory volume of air in 1 s measured during spirometric testing at ground altitude.

Dillard TA, Berg BW, Rajagopal KR, et al. Hypoxemia during air travel in patients with chronic obstructive pulmonary disease. Ann Intern Med 1989; 111:362-367

Restrictive and Interstitial Lung Disease

Predictors of Poor Performance at Altitude

- Dyspnea on exertion
- O_2 desaturation with mild exercise
- P_aO_2 < 70 mm Hg at or near sea-level
- P_aO_2 < 50 mmHg at altitude
- Moderate to severe impairment of D_LCO

Restrictive and Interstitial Lung Disease
Recommendations

- If **any one** of the predictors of poor performance at altitude are present:
  - **Do not** ascend to high altitude (> 8,000 feet)
  - Supplemental O_2 for ascent to moderate altitudes (5,000 to 8,000 feet)
    - 2 L/min if not on baseline supplemental O_2
    - If on baseline supplemental O_2 – increase flow rate by 33%

Restrictive and Interstitial Lung Disease

Prediction of P_aO_2 at 8,000 feet

$$P_aO_2 \text{ (8,000 feet)} = 0.74 + (0.39 \times [P_aO_2 \text{ sea level}]) + (0.33 \times [\text{TL,co \% predicted}])$$

P_aO_2 (8,000 feet) is the estimated arterial oxygen tension at 8,000 feet in kPa;

[P_aO_2 sea level] is the baseline arterial oxygen tension at sea level in kPa

[TL,co% predicted] is the percentage of the predicted diffusion capacity for carbon monoxide at sea level.

Christensen CC, Ryg MS, Refvem OK, et al. Effect of hypobaric hypoxia on blood gasses in patients with restrictive lung disease. Eur Respir J 2002; 20:300-305

Altitude Simulation Test

- Hypobaric chamber
  - Can simulate a variety of altitudes and duration of hypoxia, depending upon capabilities of the chamber
  - Measure arterial blood gasses before and at the end of chamber study
  - Most commonly used in research
- Hypoxic gas mixture
  - 15% O_2 for 20 minutes simulates an altitude of 8,000 feet
  - Measure arterial blood gasses before and after exposure to hypoxic gas mixture

Pulmonary Hypertension

- Patients with pulmonary hypertension (either primary or secondary) are at risk for complications at high altitude
- Even a mild increase in hypoxia at altitude may precipitate a significant increase in pulmonary artery pressure
- Considerable variability in magnitude pf hypoxia induced PA vasoconstriction

Pulmonary Hypertension

- Any degree of pulmonary hypertension is a contraindication to ascent to high altitude (i.e., altitude greater than 8,000 feet)
- Patients with Eisenmenger syndrome or severe pulmonary hypertension (Class III and IV) should not ascend above 5,000 feet – even with supplemental oxygen.
- Patients with mild to moderate (Class I and II) pulmonary hypertension may ascend to moderate altitude (5,000 to 8,000 feet) with supplemental oxygen at 2-4 L/min.

Pneumothorax

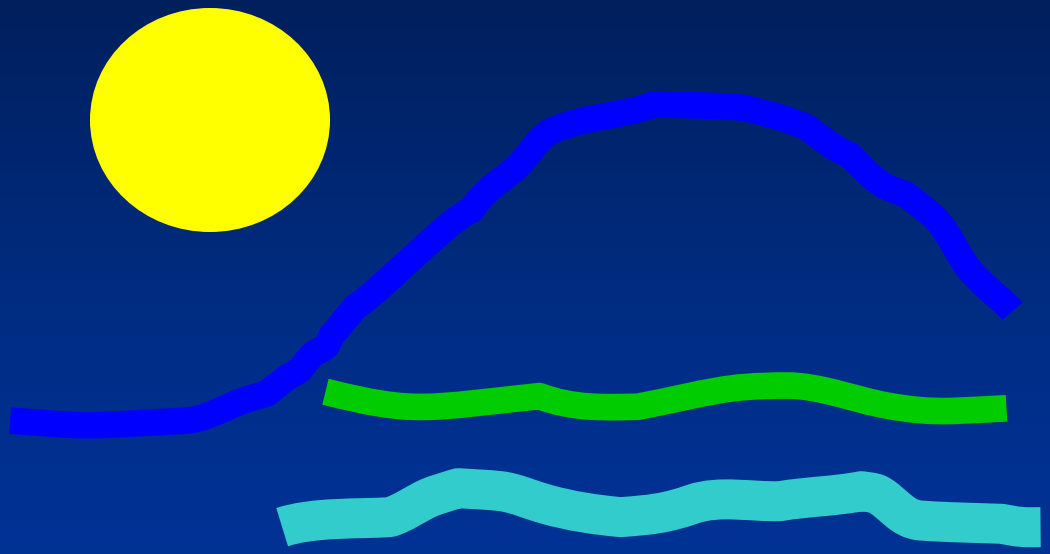
- Any evidence of pneumothorax
  - ***Absolute contraindication*** for ascent to altitudes > 5,000 ft
- After successful drainage
  - Wait 2-3 weeks before ascent to > 5,000 ft
  - F/U CXR recommended before ascent to > 5,000 ft

Cheatham ML, Safcsak K. Air travel following traumatic pneumothorax: when is it safe? Am Surg 1999; 65: 1160 – 1164.

Pneumothorax

- Patients with severe bullous emphysema who have had a previous pneumothorax from a ruptured bulla:
  - Risk of a recurrent pneumothorax is significantly greater than individuals without bullous lung disease
  - Prudent to wait at least one year after the resolution of a previous pneumothorax before considering ascent to altitude > 5,000 ft

British Thoracic Society Standards of Care Committee. Managing patients with respiratory disease planning air travel. Thorax 2002; 57: 289-304



Thank You !