Physiological High Altitude Response

M. Maggiorini
Medicla Intensive Care Unit
University Hospital Zurich

Muztagh Ata 7546m, Western China
Zone of acclimatization

Deterioration

Zone of Acclimatization
Physiologic response to hypobaric hypoxia
Altitude exposure decreases Systemic vascular resistance

16 not acclimatized subjects
- After 10, 20, 30 and 40h at each altitude (pooled results)

Systemic Vascular Resistance

\[
SVR = \frac{MAP}{CO}
\]

Cardiac output
Mean arterial BP
Total systemic vascular resistance

Vogel and Harris
J Appl Physiol 1967, 22:1124
Changes in mean cerebral artery blood flow and oxygen delivery from sea level to 7950m

Williams MH et al. Journal of Cerebral Blood Flow & Metabolism (2011) 31
Hemodynamics during exercise at different altitudes

Operation Everest II

Reeves et al J Appl Physiol 1987, 63:531
Oxygen diffusion limitation

The decreased driving pressure for oxygen from the alveolar space to arterial blood is insufficient to fully oxygenate blood as it passes through pulmonary capillaries.
Hyperventilation help to improve arterial oxygen saturation at altitude

Pt. Gnifetti 4559 m

Acclimatization
Deterioration

\[ \text{Pt. Gnifetti 4559 m} \]
Hyperventilation improves regional cerebral oxygenation ($r\text{SO}_2\%$) despite hypocapnia.

Oxygen transport at extreme altitude

CaO2 = SaO2 x Hb x 1.39 + (PaO2 x 0.03)
Physiologic response of the pulmonary circulation at altitude in adults

Hypoxic pulmonary vasoconstriction

- Ppa systolic
- Ppa mean
- Ppa diastolic
- Effective Pc
- Ppao

Euler-Liljestrand reflex

n = 14
Pulmonary artery pressure and arterial oxygenation in mountaineers during exposure to 3540 m for 3 weeks

Systolic pulmonary artery pressure

Peripheral oxygen saturation

Hilty et al. Hypoxia Symposium 2013
Remodeling of small pulmonary vessels

Muscularization of non-muscular pulmonary arterioles (~ 25 µm) within 48h

Normobaric Hypoxia 5-10% for 24h

Endothelium
Transitional cell
basal lamina

Sobin and Chen HAMB 2000, 1:311
Remodeling of small pulmonary vessels

Development of medial thickness of normally non-muscular pulmonary vessels after 9 months at HA and partial recovery after 9 months alt LA

Sobin et al. JAP 1983, 55: 1445; adapted by Reeves & Stenmark
Pulmonary artery pressure during exercise at different altitudes

Operation Everest II: Pulmonary artery driving pressure (mPpa-Ppao)

Response of the pulmonary circulation to hypobaric hypoxia

Mean pulmonary artery pressure differences between lowlanders and high altitude residents

- Andes 4260 m
- Andes 3690 m
- Tibetan 3658 m
- Lowlanders at 4559 m
- Lowlanders at SL

30 mmHg

Lung Nitric-Oxide turnover among different population

Exhaled Nitric Oxide concentration in Tibetans (4200m), Bolivian Aymara (3900m) and Low Landers (reference sample from the US)

Thank you for your attention