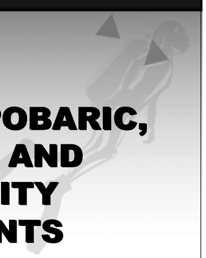
CHAPTER 11

EXERCISE IN HYPOBARIC, HYPERBARIC, AND MICROGRAVITY ENVIRONMENTS



Learning Objectives

- Find out what conditions in hypobaric environments (at altitude) limit or contribute to different types of physical activity.
- Learn the physiological adjustments that accompany acclimatization to altitude.
- Discern whether an endurance athlete who trains at altitude can perform better at sea-level.
- Discover what conditions and health risks are unique to hypobaric environments (underwater).

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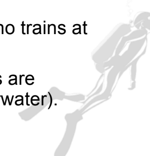


Learning Objectives

- Learn what physiological and pathological problems face scuba divers who descend 30 m or more.
- Examine what happens to muscles, bones, and blood in a microgravity environment (in space).
- Find out how $\dot{V}O_2max$ changes with prolonged exposure to microgravity and what countermeasures can assist an astronaut on his or her return to Earth.

Conditions at Altitude

- At least 1,500 m (4,921 ft) above sea level
- Reduced barometric pressure (hypobaric)
- Reduced partial pressure of oxygen (PO_2)
- Reduced air temperature
- Low humidity
- Increase in solar radiation intensity

Changes in Barometric Pressure (P_B) and Partial Pressure of Oxygen (PO_2) at Different Altitudes

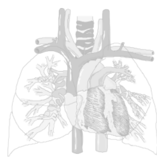
Altitude (m)	P_B (mmHg)	PO_2 (mmHg)
0 (sea level)	760	159.2
1,000	674	141.2
2,000	596	124.9
3,000	526	110.2
4,000	462	96.9
9,000	231	48.4

Did You Know…?

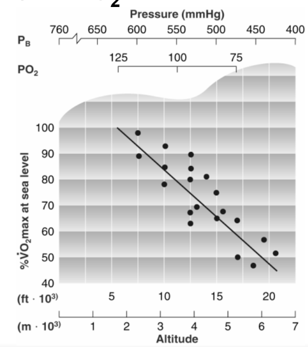
The reduction in PO_2 at altitude affects the partial pressure gradient between the blood and the tissues and thus oxygen transport. This explains the decrease in endurance sports performance at altitude.

Respiratory Responses to Altitude

- Pulmonary ventilation increases.
- Pulmonary diffusion does not change.
- Oxygen transport is slightly impaired.
- Oxygen uptake is impaired.
- As the PO_2 decreases, $\dot{V}O_2$max decreases at a progressively greater rate.



CHANGES IN $\dot{V}O_2$MAX WITH ALTITUDE



Did You Know…?

Altitude does not affect $\dot{V}O_2$max until approximately 1,600 m (5,294 ft). Above this level, the decrease in $\dot{V}O_2$max is approximately 11% for every 1,000 m (3,281 ft).

Cardiovascular Responses to Altitude

- Initial decrease in plasma volume (more red blood cells per unit)
- Initial increase in HR, SV, and $\dot{Q}$ during submaximal work to compensate for less O_2
- Decrease in HR, SV, and $\dot{Q}$max during maximal work, which limits oxygen delivery and uptake.

Metabolic Responses to Altitude

- Increase in anaerobic metabolism
- Increase in lactic acid production
- Less lactic acid production at maximal work rates at altitude than at sea level

Key Points

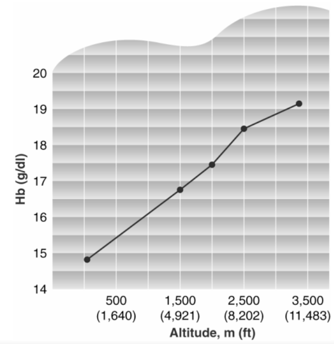
Performance at Altitude

- At altitude, endurance activity is affected the most due to reliance on oxygen transport and the aerobic energy system.
- Endurance athletes can prepare for competitions at altitude by performing high-intensity endurance training at any elevation to increase their $\dot{V}O_2$max.
- Anaerobic sprint activities are the least affected by altitude.
- The thinner air at altitude provides less aerodynamic resistance and less gravitational pull, thus potentially improving jumping and throwing events.

Acclimatization to Altitude

- Increase in number of red blood cells
- Decrease in plasma volume
- Increase in hemoglobin content and blood viscosity
- Decrease in muscle fiber areas and total muscle area
- Increase in capillary density
- Increase in pulmonary ventilation
- Decrease in $\dot{V}O_2$max with initial exposure does not improve much

Hb CONCENTRATIONS AND ALTITUDE



Altitude Training for Sea-Level Performance

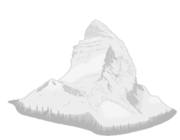
- Increases red blood cell mass on return to sea level
- Not proven that altitude training improves sea-level performance
- Difficult to study since intensity and volume are reduced at altitude
- Live at high altitude and train at lower altitudes

Training for Optimal Altitude Performance

- Compete within 24 hours of arrival to altitude
- Train at 1,500 to 3,000 m above sea level for at least 2 weeks before competing
- Increase $\dot{V}O_2$max at sea level to be able to compete at a lower relative intensity

Acute Altitude Sickness

- Nausea, vomiting, dyspnea, insomnia
- Appears 6 to 96 h after arrival at altitude
- May result from carbon dioxide accumulation
- Avoid by ascending no more than 300 m (984 ft) per day above 3,000 m (9,843 ft)



High-Altitude Pulmonary Edema (HAPE)

- Shortness of breath, excessive fatigue, blue lips and fingernails, mental confusion
- Occurs after rapid ascent above 2,700 m (8,858 ft)
- Accumulation of fluid in the lungs which interferes with air movement
- Cause unknown
- Administer supplemental oxygen and move to lower altitude

High-Altitude Cerebral Edema (HACE)

- Mental confusion, progressing to coma and death
- Most cases occur above 4,300 m (14,108 ft)
- Accumulation of fluid in cranial cavity
- Cause unknown
- Administer supplemental oxygen and move to lower altitude

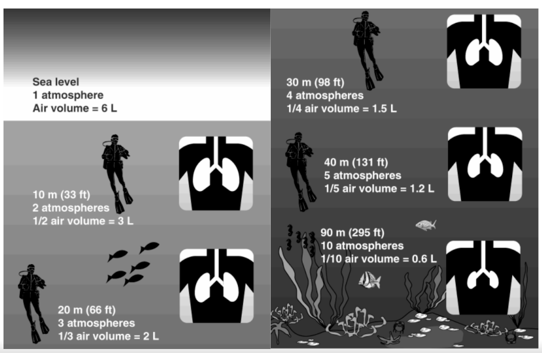
Water Immersion and Gas Pressures

Pressure underwater is greater than at sea level.

As pressure increases, volume decreases.

- Descent—external pressure increases.
- Submersion—air already in the body compresses.
- Ascent—air taken in at depth expands.

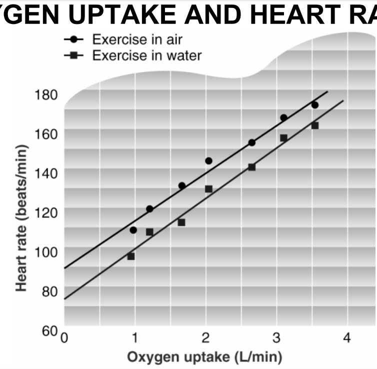
WATER DEPTH AND AIR VOLUME



Cardiovascular Responses to Immersion

- Cardiovascular workload decreases
- Plasma volume increases
- Heart rate decreases (even more in cold water)
- At a given exercise effort, heart rate is lower

OXYGEN UPTAKE AND HEART RATE



Key Points

Breath-Hold Diving

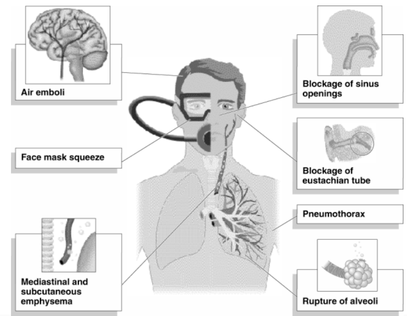
- Urge to breathe is due to build up of arterial CO_2.
- Gases in body can reduce to no smaller than residual volume.
- Depth limit is determined by the TLV:RV ratio.
- Individuals with larger TLV:RV ratios can dive deeper than those with smaller ratios.

Key Points

Scuba Diving

- A self-contained underwater breathing apparatus (scuba) pressurizes the air breathed underwater.
- Scuba equipment includes:
  - Tank(s) of highly compressed air,
  - First-stage regulator valve to reduce air pressure for breathing,
  - Second-stage regulator that releases air at pressure equal to the water, and
  - One-way breathing valve.
- The length of a dive depends on the diver's depth.

HEALTH RISKS OF HYPERBARIC CONDITIONS



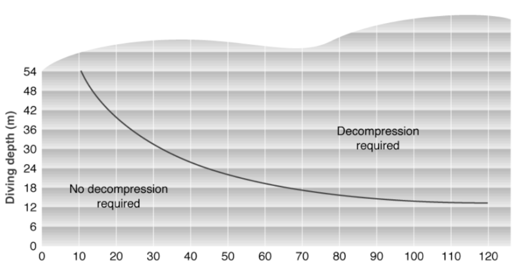
Oxygen Poisoning

- PO_2 values exceed 318 mmHg
- Visual distortion, rapid and shallow breathing, and convulsions
- Tissues are not able to remove O_2 from hemoglobin
- Hemoglobin is then not able to remove CO_2
- High PO_2 causes vasoconstriction to cerebral vessels

Decompression Sickness

- Results from ascending too rapidly
- Aching in elbows, shoulders, and knees, can cause emboli in blood
- Nitrogen bubbles become trapped in body
- Treat by placing diver in recompression chamber
- Prevent by using chart showing time to ascend from various depths

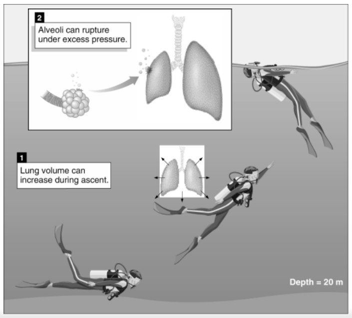
DECOMPRESSION DURING DIVING



Nitrogen Narcosis

- Nitrogen acts like anaesthetic gas
- Similar to alcohol intoxication
- Depth and pressure increases worsen it
- Also called rapture of the deep

PNEUMOTHORAX AND EMBOLI FORMATION



Did You Know…?

The Navy uses a technique called saturation diving to enable divers to stay at great depths for long periods of time. At a given depth, the amount of nitrogen that can dissolve in the body tissues is limited. By staying in a pressurized environment for 24 hours, the body tissues become saturated, after which the tissues do not absorb any more inactive gas for as long as the diver stays at that depth.

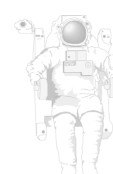
Key Points

Microgravity Environments

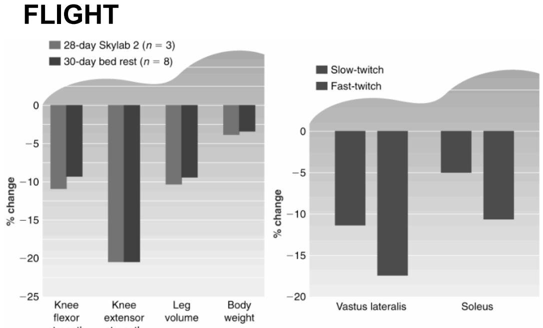
- 1 g is the standard acceleration produced by gravity.
- Microgravity describes conditions where gravitational force is less than 1 g.
- Microgravity is used to describe conditions in space that aren't always 0 g.
- The effects of microgravity on the body are similar to the effects of detraining.

Exercise in Microgravity Environments

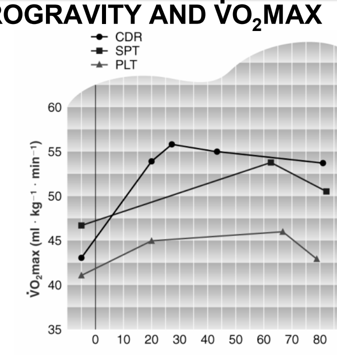
- Muscle strength decreases
- Cross-sectional areas of ST and FT fibers decrease
- Bone mineral content in weight-bearing bones decreases
- Plasma volume decreases
- Transient cardiac output and arterial blood pressure increases
- Weight decreases (mostly from fluid loss)



EFFECTS OF BED REST vs SPACE FLIGHT



MICROGRAVITY AND $\dot{V}O_2$MAX



Did You Know…?

Research shows that exercise during spaceflight may be an effective countermeasure to prepare astronauts for successful adaptation on return to earth. The type and amount of exercise that produces the best results is still under debate.