Chapter 8

Pulmonary Adaptations to Exercise

The Respiratory System

Conducting zone ("Dead Space") - consists of the mouth, nasal cavity and passages, pharynx and trachea which collectively *connect the respiratory zone of the lung to the atmospheric air* surrounding the body.

Respiratory zone - consists of the respiratory bronchioles, aveoli ducts, and alveoli which collectively represent the *sites of pulmonary gas exchange*.

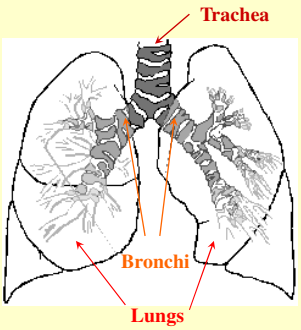
Pulmonary circulation - artery, arteriole, capillary and vein network that directs blood flow from the right ventricle of the heart to the lungs, and back to the left atrium of the heart.

Note:

The conducting zone is the region of greatest resistance.

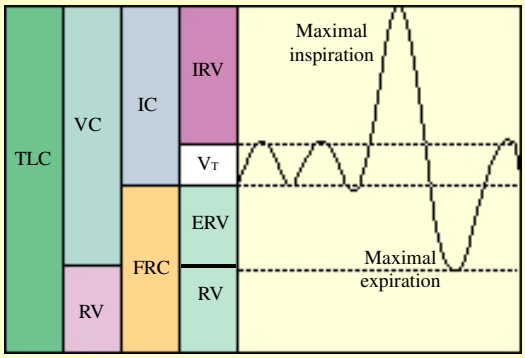
The respiratory zone has the greatest surface area and a dense capillary network.

Distribution of surfactant is aided by holes that connect alveoli called pores of Kohn.



Lung Volumes and Capacities

Figure 8.3



Ventilation

The movement of air into and from the lung by the process of bulk flow.

Ventilation (V_E) (L/min) = frequency (br/min) x tidal volume (L) **(8.1)**

For rest conditions,

V_E (L/min) = 12 (br/min) x 0.5 (L) = 6 L/min

For exercise at VO_2max,

V_E (L/min) = 60 (br/min) x 3.0 (L) = 180 L/min

Compliance - *the property of being able to increase size or volume with only small changes in pressure.*

Alveolar Ventilation

The volume of "fresh" air that reaches the respiratory zone of the lung.

Alveolar Ventilation (V_A) (L/min)

V_A = frequency (br/min) x (tidal volume - 0.15) (L)

For normal breathing conditions,

V_A = 12 (br/min) x (1.0 - 0.15) (L) **(8.2a)**

= 12 x 0.85 = 10.2 L/min

For rapid shallow breathing conditions,

V_A = 60 (br/min) x (0.2 - 0.15) (L) **(8.2b)**

= 60 x 0.05 = 3.0 L/min

Surfactant

A phospholipoprotein molecule, secreted by specialized cells of the lung, that *lines the surface of alveoli and respiratory bronchioles*. Surfactant *lowers the surface tension* of the alveoli membranes, *preventing the collapse* of alveoli during exhalation and *increasing compliance* during inspiration.

Respiration

The process of gas exchange, which for the human body involves oxygen (O_2) and carbon dioxide (CO_2).

Internal respiration - at the cellular level

External respiration - at the lung

Gas Partial Pressures in Atmospheric and Alveolar Air

Gas	Air* Fraction	Air* Partial Pressure	Alveolar Fraction^	Alveolar Partial Pressure
H_2O	0	0	----	47
O_2	0.2093	159.0	0.1459	104
CO_2	0.0003	0.3	0.0561	40
N_2	0.7903	600.6	0.7980	569

* assumes dry air

^ note that the water vapor pressure is removed to calculate alveolar gas fractions

Diffusion of Gases

The gases of respiration (O_2 and CO_2) diffuse down pressure gradients that exist between,

a. pulmonary blood and the alveoli

b. systemic capillary blood and cells

The factors that govern the directionality and magnitude of gas diffusion are,

- the gas diffusion capacity
- the gas partial pressure gradient
- characteristics of the medium through which diffusion occurs (hydration, thickness, cross sectional area)

Transport of Oxygen in the Blood

Oxygen is transported in blood bound to **hemoglobin** (Hb). 1 gram of Hb can maximally bind 1.34 mL of oxygen (1.34 mL O_2/g Hb @ 100% saturation).

Table 8.1: Examples of hemoglobin (Hb) and oxygen carrying capacity conditions (98% saturation and pH = 7.4)

Population/Condition	*[Hb]*	*mL O_2/L*
Males	14.0	183.8
Females	12.0	157.6
Blood Doping	18.0	236.4
Anemia	< 10.0	< 131.3

[Hb] = g/100 mL

The oxygen content (CaO_2) of blood can be calculated by;

CaO_2 = [Hb] x O_2/g Hb x Hb-O_2 saturation **(8.3)**

= 150 g/L x 1.34 mL O_2/g x 0.98

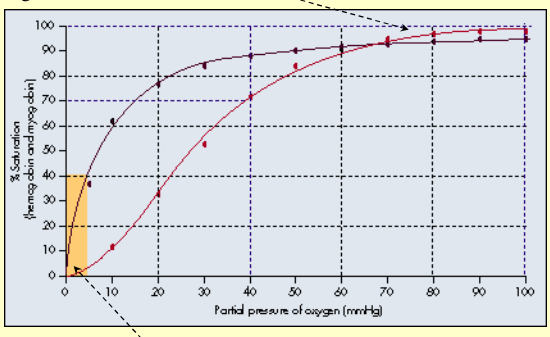
= 197 mL O_2/L

Another small source of oxygen in blood is the volume of *oxygen dissolved in plasma*. However, due to the low solubility of oxygen,this value is small and approximates,

dissolved O_2 = 0.003 mL / 100 mL blood / mmHg PO_2

~ 0.3 mL / 100 mL at sea level (PaO_2 ~ 100 mmHg)

Figure 8.6 *Note the relatively flat region of the curve*



Note the small range of PO_2 in muscle during exercise

Transport of Carbon Dioxide in the Blood

The volume of CO_2 in the blood is approximately 10-fold greater than O_2.

Transport Location	*Form*	*Percentage*
Plasma	Dissolved	5
(<10%)	$CO_2 + H_2O \rightarrow H_2CO_3 \rightarrow H^+ + HCO_3^-$	<1
	Bound to proteins	5
Red Blood Cell	$CO_2 + H_2O \rightarrow H_2CO_3 \rightarrow H^+ + HCO_3^-$	65
(90%)	Dissolved	5
	Bound to hemoglobin	20

Acidosis

Quantified by the pH scale, where pH equals the negative logarithm of the hydrogen ion concentration ($[H^+]$)

$$pH = - \log [H^+] \quad \text{or} \quad [H^+] = 10^{-pH}$$

Normal blood pH is ~7.4.

The main determinants of blood pH are;

- Rate of acid production
- Concentration of HCO_3^- and other bases or acids
- $PaCO_2$
- Ventilation
- Renal excretion of acids and bases

Acute Adaptations of Pulmonary Function During Exercise

After the onset of exercise there is;

- a rapid ↑ in ventilation
- a similar rapid ↑ in pulmonary blood flow
- an improved V_E vs Q relationship in the lung
- ↑ lung compliance
- airway dilation and ↓ resistance to air flow