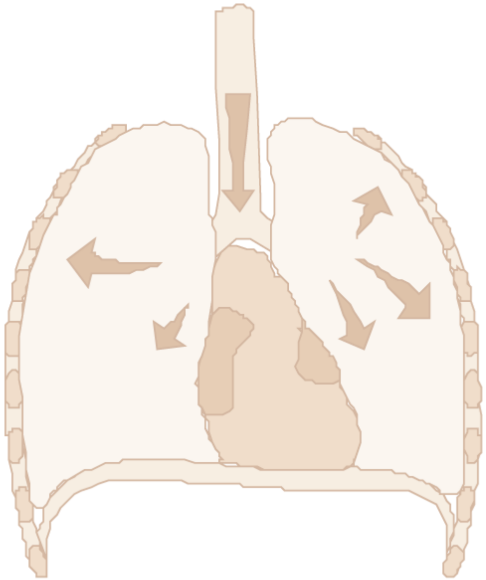
RESPIRATORY REGULATION DURING EXERCISE

Respiration

Respiration—delivery of oxygen to and removal of carbon dioxide from the tissue

External respiration—ventilation and exchange of gases in the lung

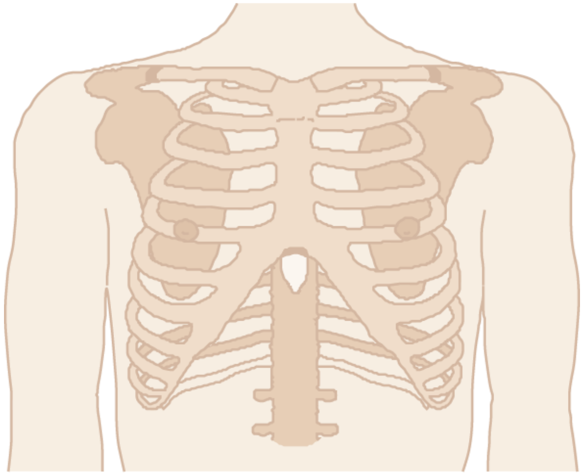
Internal respiration—exchange of gases at the tissue level (between blood and tissues)



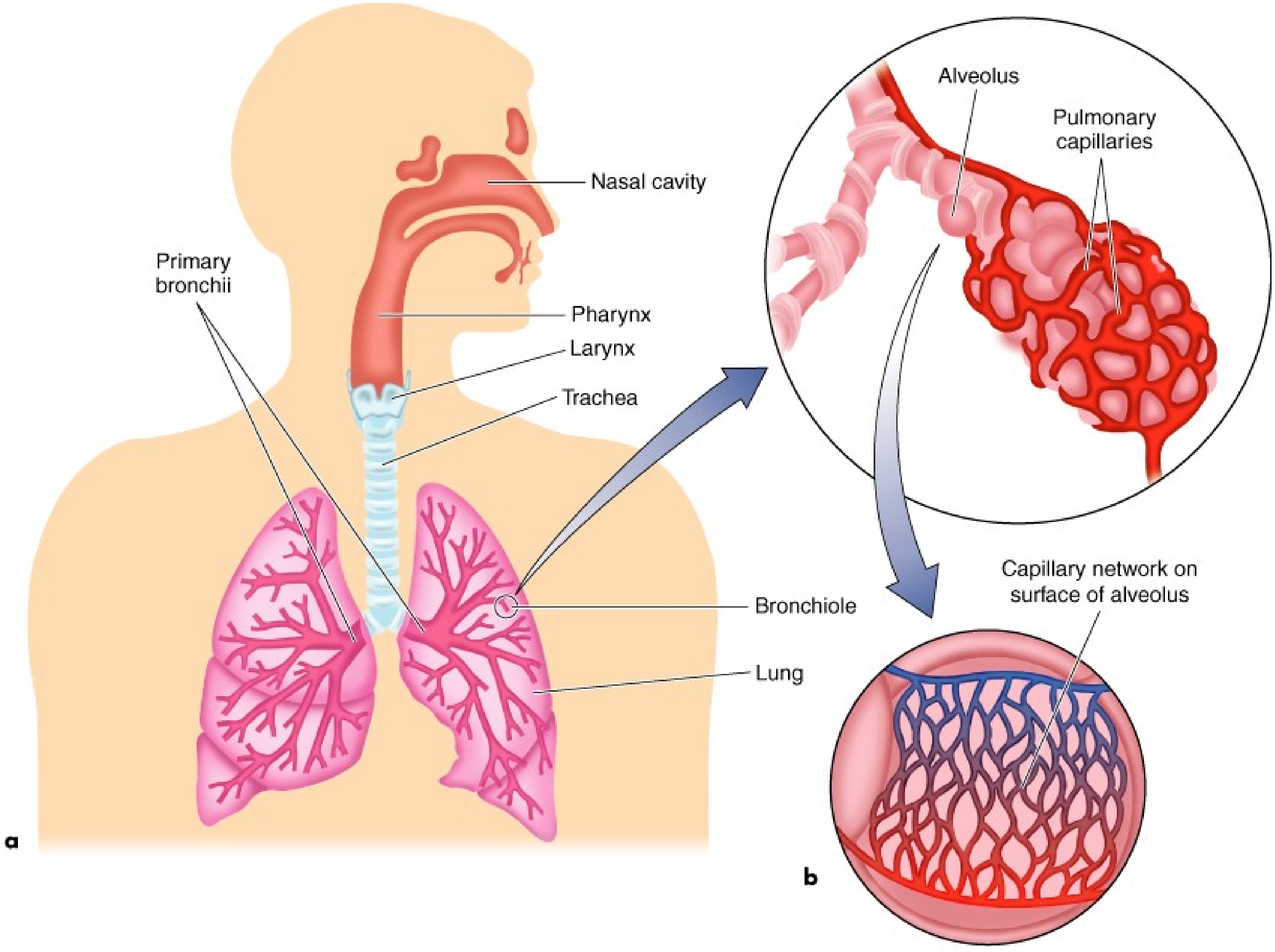
External Respiration

Pulmonary ventilation—movement of air into and out of the lungs—inspiration and expiration

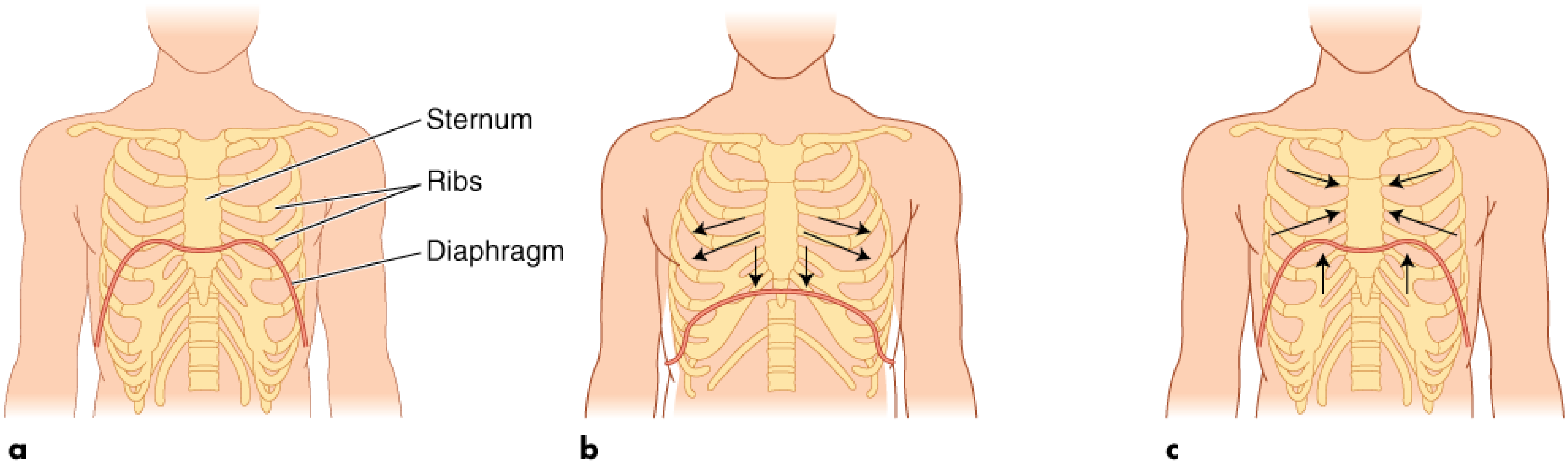
Pulmonary diffusion—exchange of oxygen and carbon dioxide between the lungs and blood



RESPIRATORY SYSTEM



INSPIRATION AND EXPIRATION



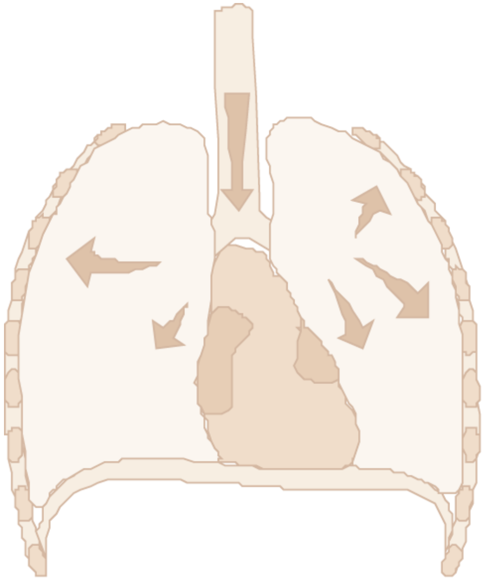
Rest

Inspiration

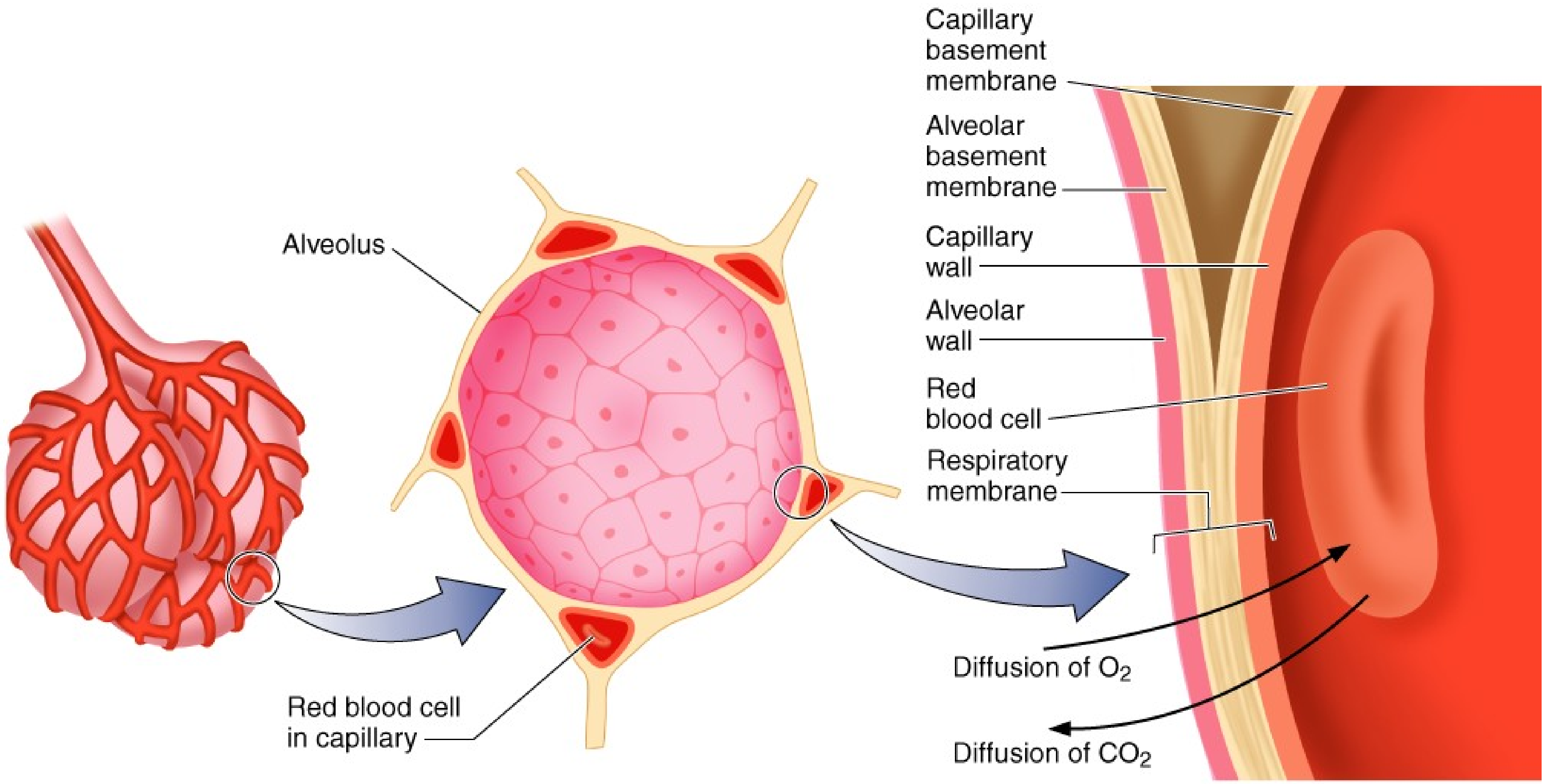
Expiration

Pulmonary Diffusion

- Replenishes blood's oxygen supply that has been depleted for oxidative energy production
- Removes carbon dioxide from returning venous blood
- Occurs across the thin respiratory membrane



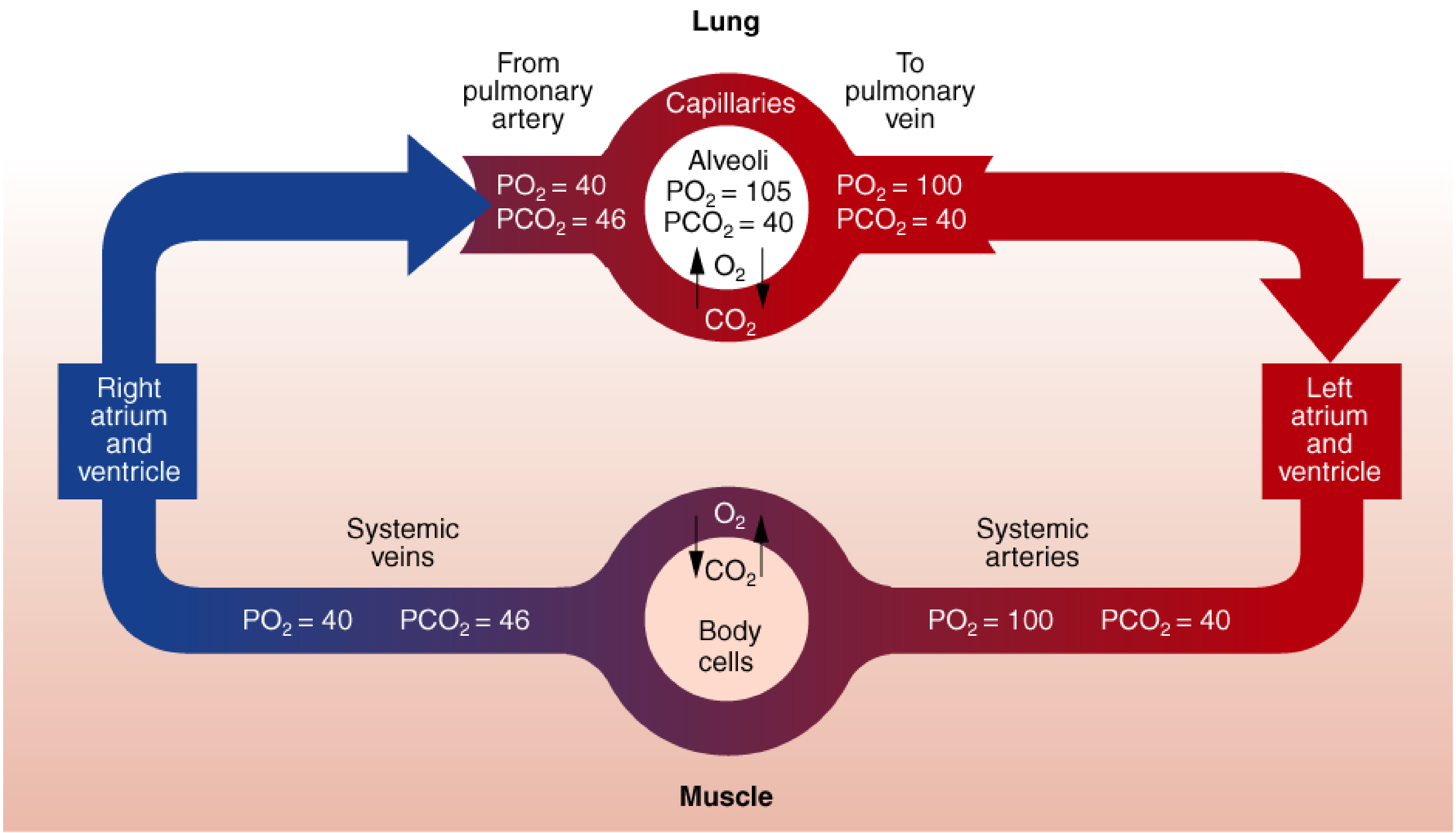
RESPIRATORY MEMBRANE



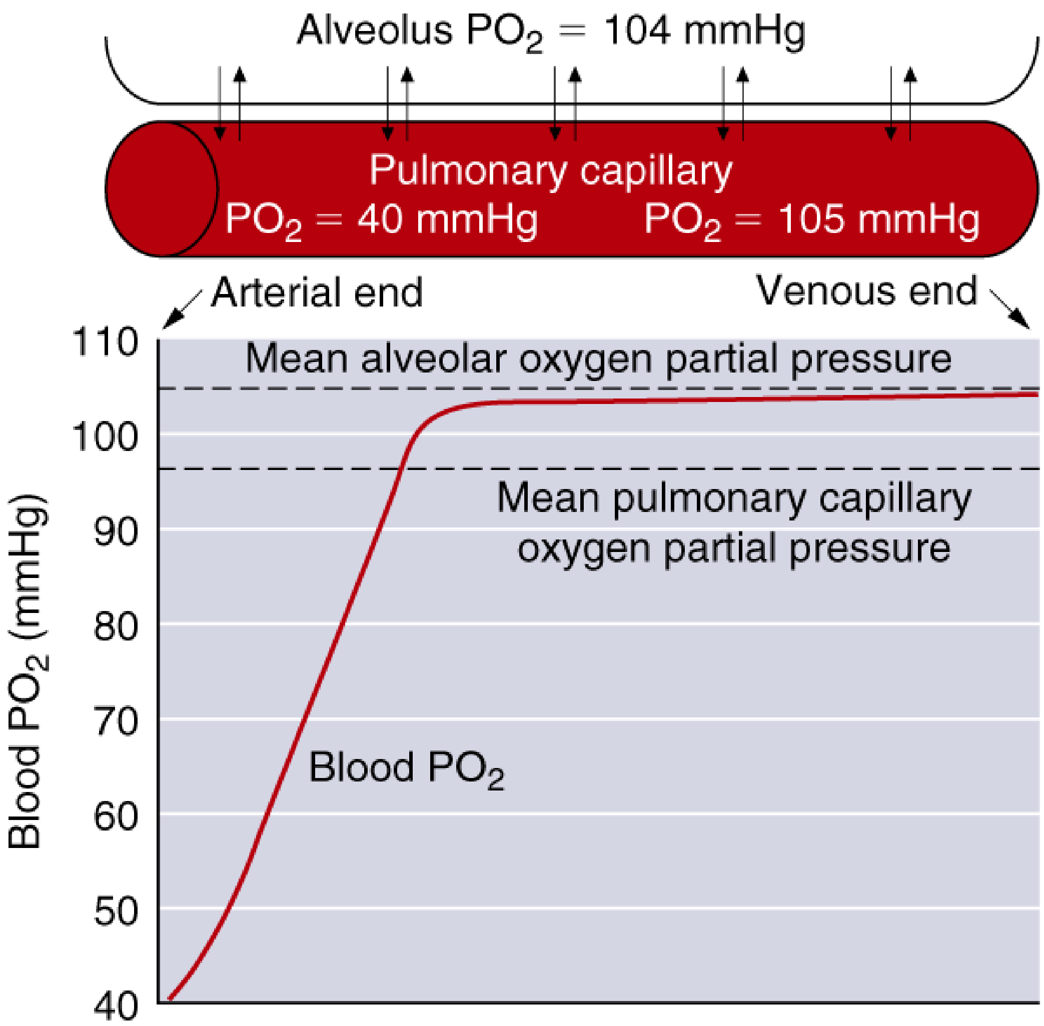
Did You Know…?

Differences in the partial pressures of gases in the alveoli and in the blood create a pressure gradient across the respiratory membrane. This difference in pressures leads to diffusion of gases across the respiratory membrane. The greater the pressure gradient, the more rapidly oxygen diffuses across it.

PO_2 AND PCO_2 IN BLOOD



UPTAKE OF OXYGEN INTO PULMONARY CAPILLARY



Partial Pressures of Respiratory Gases at Sea Level

Gas	% in dry air	Partial pressure (mmHg) Dry air	Alveolar air	Arterial blood	Venous blood	Diffusion gradient
Total	100.00	760.0	760	760	706	0
H_2O	0.00	0.0	47	47	47	0
O_2	20.93	159.1	105	100	40	60
CO_2	0.03	0.2	40	40	46	6
N_2	79.04	600.7	568	573	573	0

Key Points

Pulmonary Diffusion

- Pulmonary diffusion is the process by which gases are exchanged across the respiratory membrane in the alveoli to the blood and vice versa.
- The amount of gas exchange depends on the partial pressure of each gas, its solubility, and temperature.
- Gases diffuse along a pressure gradient, moving from an area of higher pressure to lower pressure.

(continued)

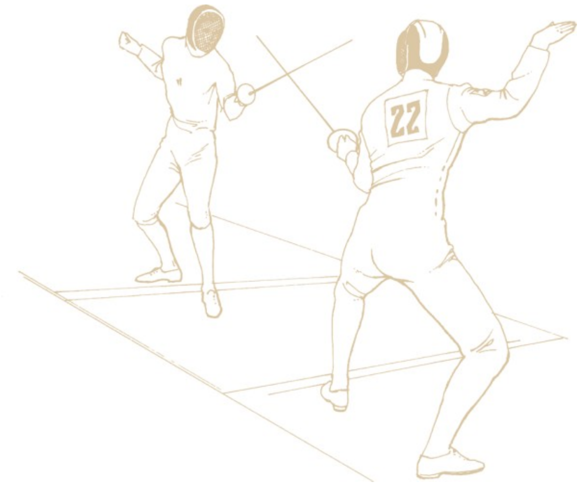
Key Points

Pulmonary Diffusion

- Oxygen diffusion capacity increases as you move from rest to exercise.
- The pressure gradient for CO_2 exchange is less than for O_2 exchange, but carbon dioxide's diffusion coefficient is 20 times greater than that of oxygen's, so CO_2 crosses the membrane easily.

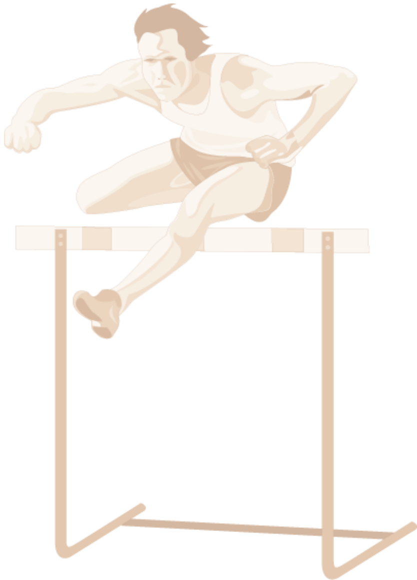
Oxygen Transport

- Hemoglobin concentration largely determines the oxygen-carrying capacity of blood (>98% of oxygen transported).
- Increased H^+ (acidity) and temperature of a muscle allows more oxygen to be unloaded there.
- Training affects oxygen transport in muscle.



Carbon Dioxide Transport

- Dissolved in blood plasma (7% to 10%)
- As bicarbonate ions resulting from the dissociation of carbonic acid (60% to 70%)
- Bound to hemoglobin (carbaminohemoglobin) (20% to 33%)



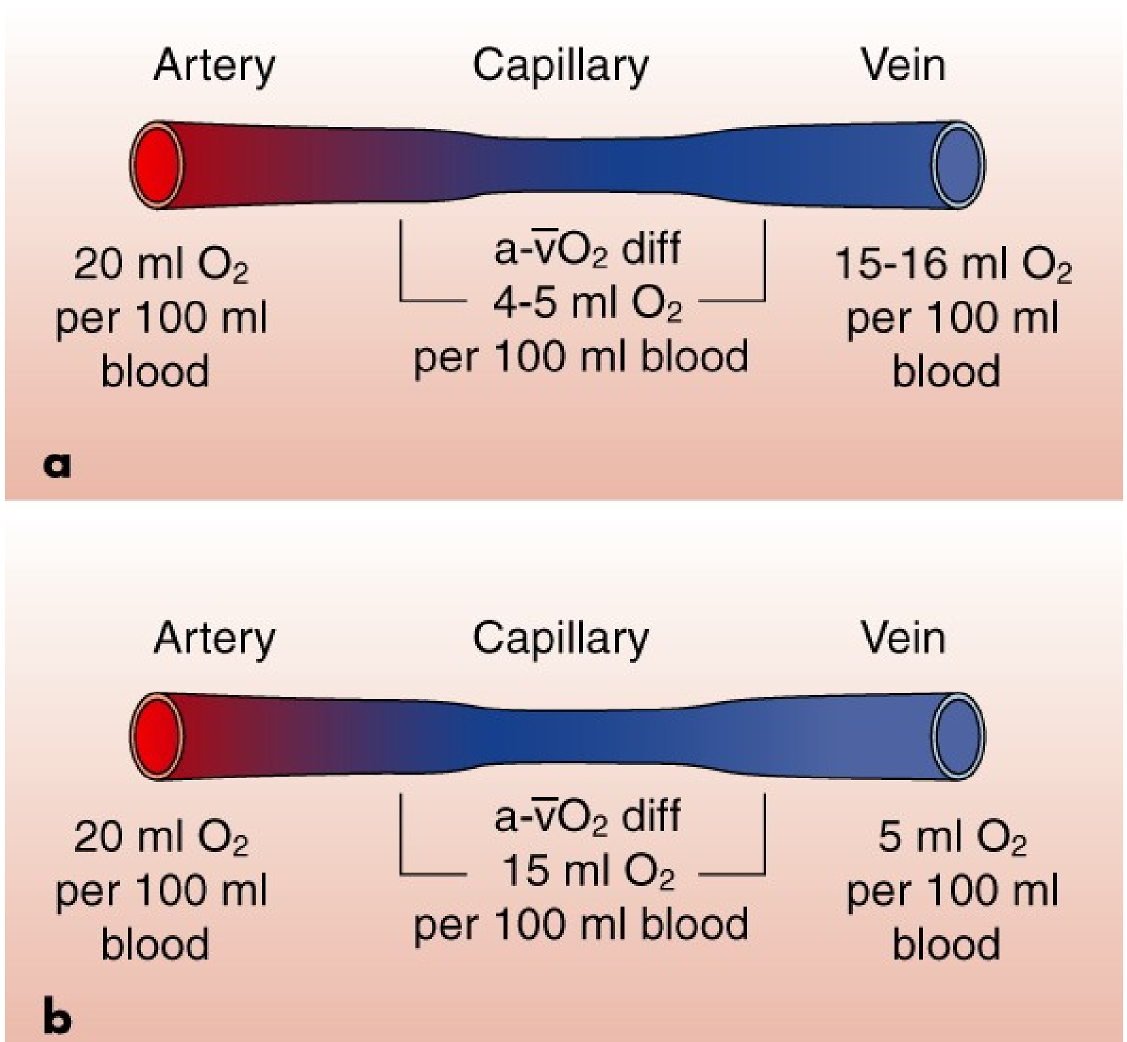
The a-$\bar{v}O_2$ diff—Arterial O_2 Content

- Hemoglobin (Hb)—1 molecule of Hb carries 4 molecules of O_2, and 100 ml of blood contains ~14-18 g of Hb in men and ~12-14 in women (1 g of Hb combines with 1.34 ml of oxygen).
- There are ~20.1 ml of O_2 per 100 ml of arterial blood (15 g of Hb × 1.34 ml of O_2/g of Hb) in men and ~17.4 ml of O_2 per 100 ml of arterial blood (13 g × 1.34) in women.
- Low iron leads to iron-deficiency anemia, reducing the body's capacity to transport oxygen—this is more of a problem in women than men.

THE a-$\bar{v}O_2$ DIFF ACROSS THE LUNG

Rest

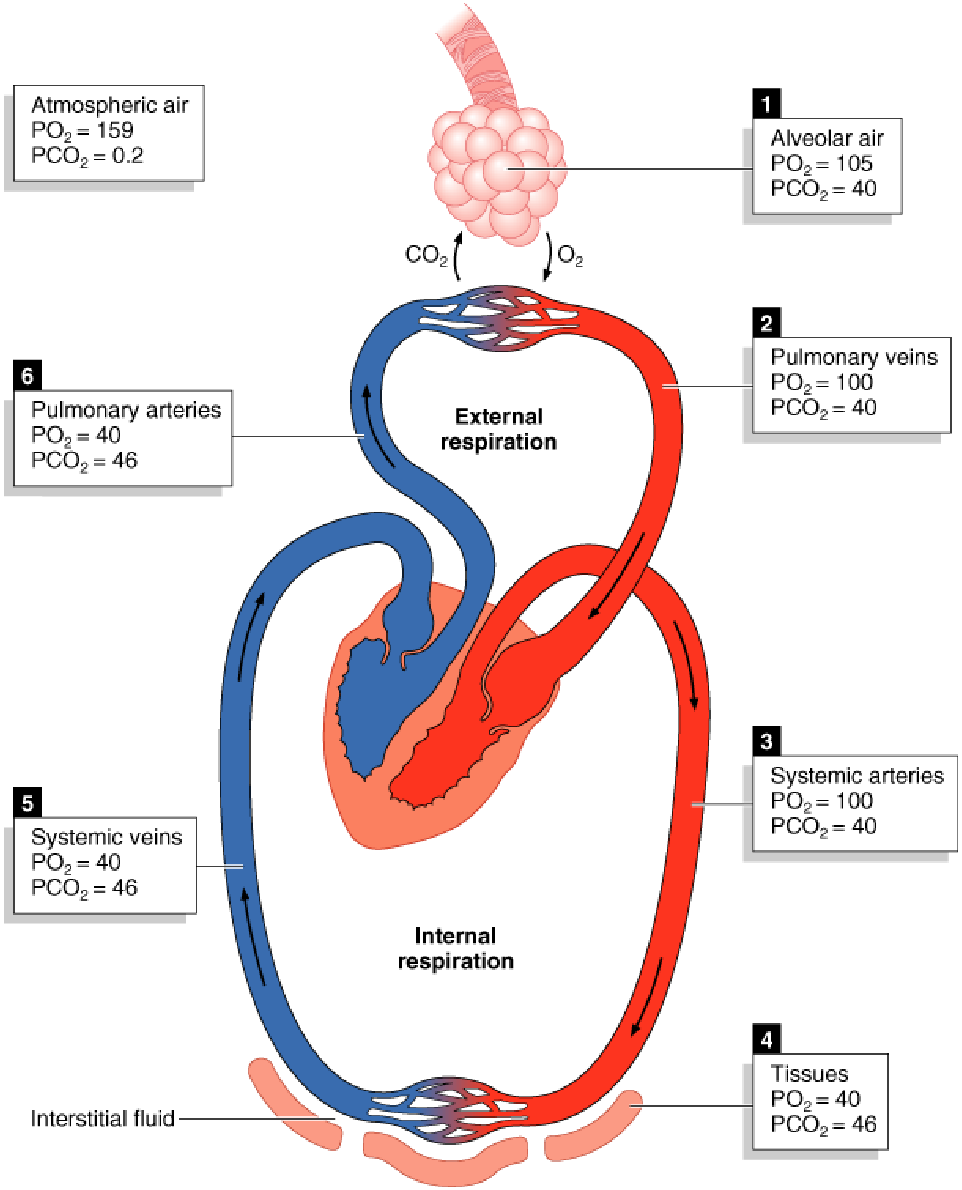
Maximal exercise



Factors of Oxygen Uptake and Delivery

1. Oxygen content of blood
2. Amount of blood flow
3. Local conditions within the muscle

EXTERNAL AND INTERNAL RESPIRATION



Key Points

External and Internal Respiration

- Oxygen is largely transported in the blood bound to hemoglobin and in small amounts by dissolving in blood plasma.
- Hemoglobin saturation decreases when PO_2 or pH decreases, or if temperature increases. These factors increase oxygen unloading in a tissue that needs it.
- Hemoglobin is usually 98% saturated with oxygen which is higher than what our bodies require, so the blood's oxygen-carrying capacity seldom limits performance.

(continued)

Key Points

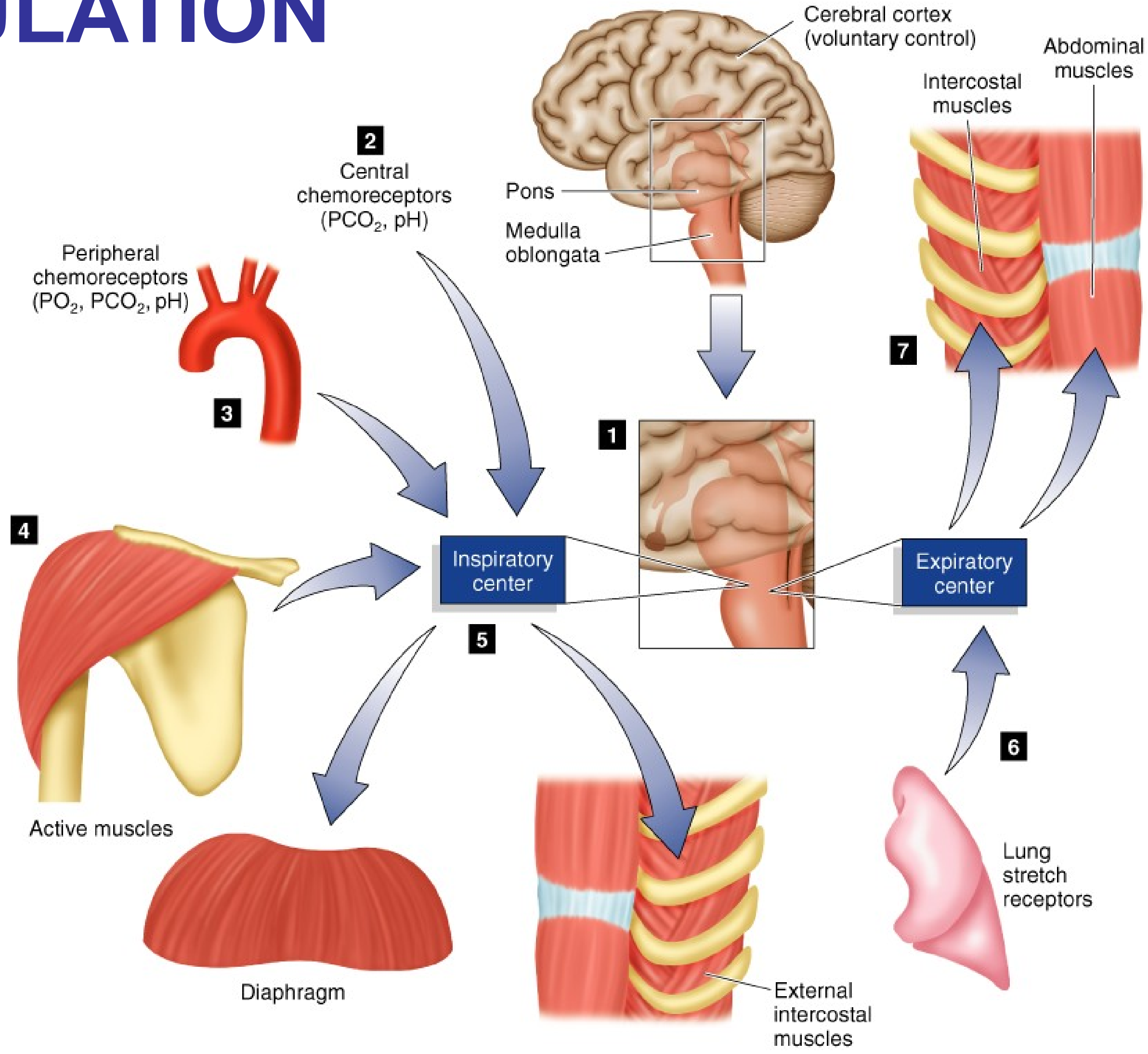
External and Internal Respiration

- Carbon dioxide is transported in the blood as bicarbonate ion, in blood plasma or bound to hemoglobin.
- The $a\text{-}\bar{v}O_2$ diff—difference in the oxygen content of arterial and mixed venous blood—reflects the amount of oxygen taken up by the tissues.
- Carbon dioxide exchange at the tissues is similar to oxygen exchange except that it leaves the muscles and enters the blood to be transported to the lungs for clearance.

Regulators of Pulmonary Ventilation at Rest

- Higher brain centers
- Chemical changes within the body
- Chemoreceptors
- Muscle mechanoreceptors
- Hypothalamic input
- Conscious control

RESPIRATORY REGULATION



Breathing frequency (BF)

Brathing frequency is the number of breaths taken within a set amount of minute:

BF rest = 16 (breaths per minute) (10 in endurance)

BF (light exercise) = 20-30

BF (moderate exercise) = 30-40

BF (heavy exercise) = 50-60

Tidal volume (VT)

Tidal volume (l) is the amount of air inspired or expired during normal quiet respiration.

V_T rest = 0,5 l (1 l in endurance)

V_T (light exercise) = 1-1,5 l

V_T (moderate exercise) = 1,5-2 l

V_T (heavy exercise) = 2-3 l

Pulmonary Ventilation

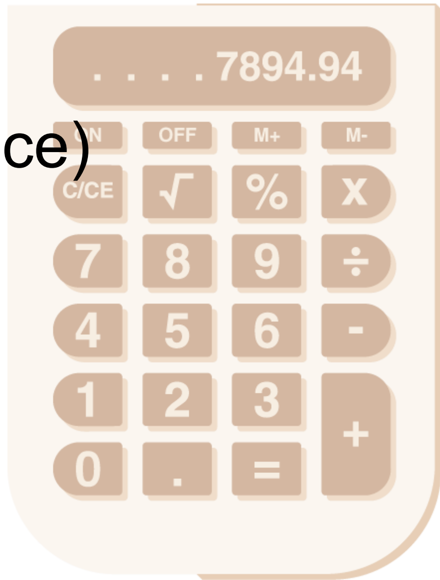
Ventilation ($\dot{V}_E$) is the product of tidal volume (TV) and breathing frequency (f):

$\dot{V}_E$ rest = 8 l

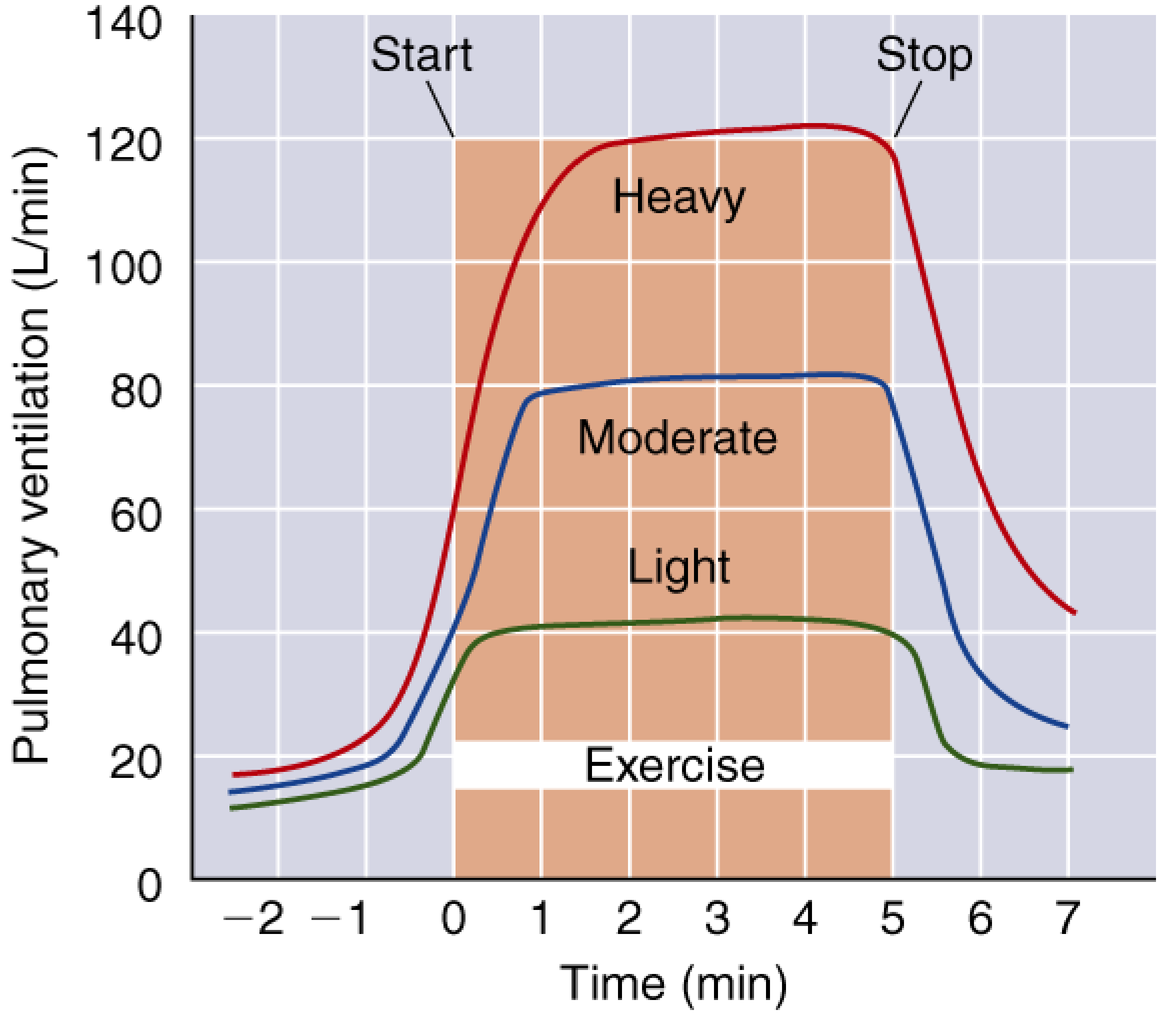
V_E (light exercise) = 40 l

V_E (moderate exercise) = 80 l

V_E (heavy exercise) = 120l (180l in endurance)



VENTILATORY RESPONSE TO EXERCISE



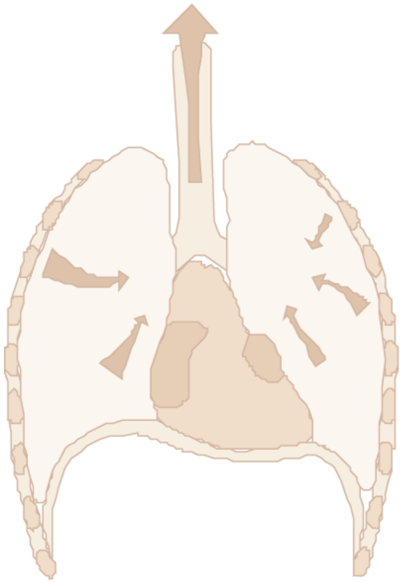
Breathing Terminology

Dyspnea—shortness of breath.

Hyperventilation—increase in ventilation that exceeds the metabolic need for oxygen. Voluntary hyperventilation, as is often done before underwater swimming, reduces the ventilatory drive by increasing blood pH.

Ventilatory Equivalent for Oxygen

- The ratio between $\dot{V}_E$ and $\dot{V}O_2$ in a given time frame
- Indicates breathing economy
- At rest—$\dot{V}_E/\dot{V}O_2$ = 23 to 28 L of air breathed per L $\dot{V}O_2$ per minute
- At max exercise—$\dot{V}_E/\dot{V}O_2$ = 30 L of air per L $\dot{V}O_2$ per minute
- Generally $\dot{V}_E/\dot{V}O_2$ remains relatively constant over a wide range of exercise levels

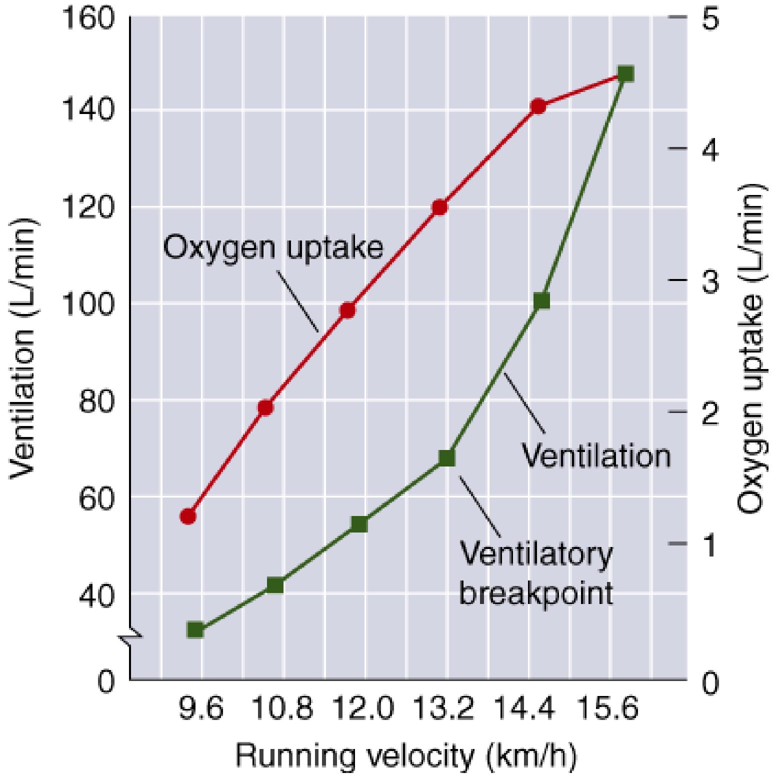


Ventilatory Breakpoint

- The point during intense exercise at which ventilation increases disproportionately to the oxygen consumption.
- When work rate exceeds 55% to 70% $\dot{V}O_2$max, oxygen delivery can no longer match the energy requirements so energy must be derived from anaerobic glycolysis.
- Anaerobic glycolysis increases lactate levels, which increase CO_2 levels (buffering), triggering a respiratory response and increased ventilation.

$\dot{V}_E$ AND $\dot{V}O_2$ DURING EXERCISE

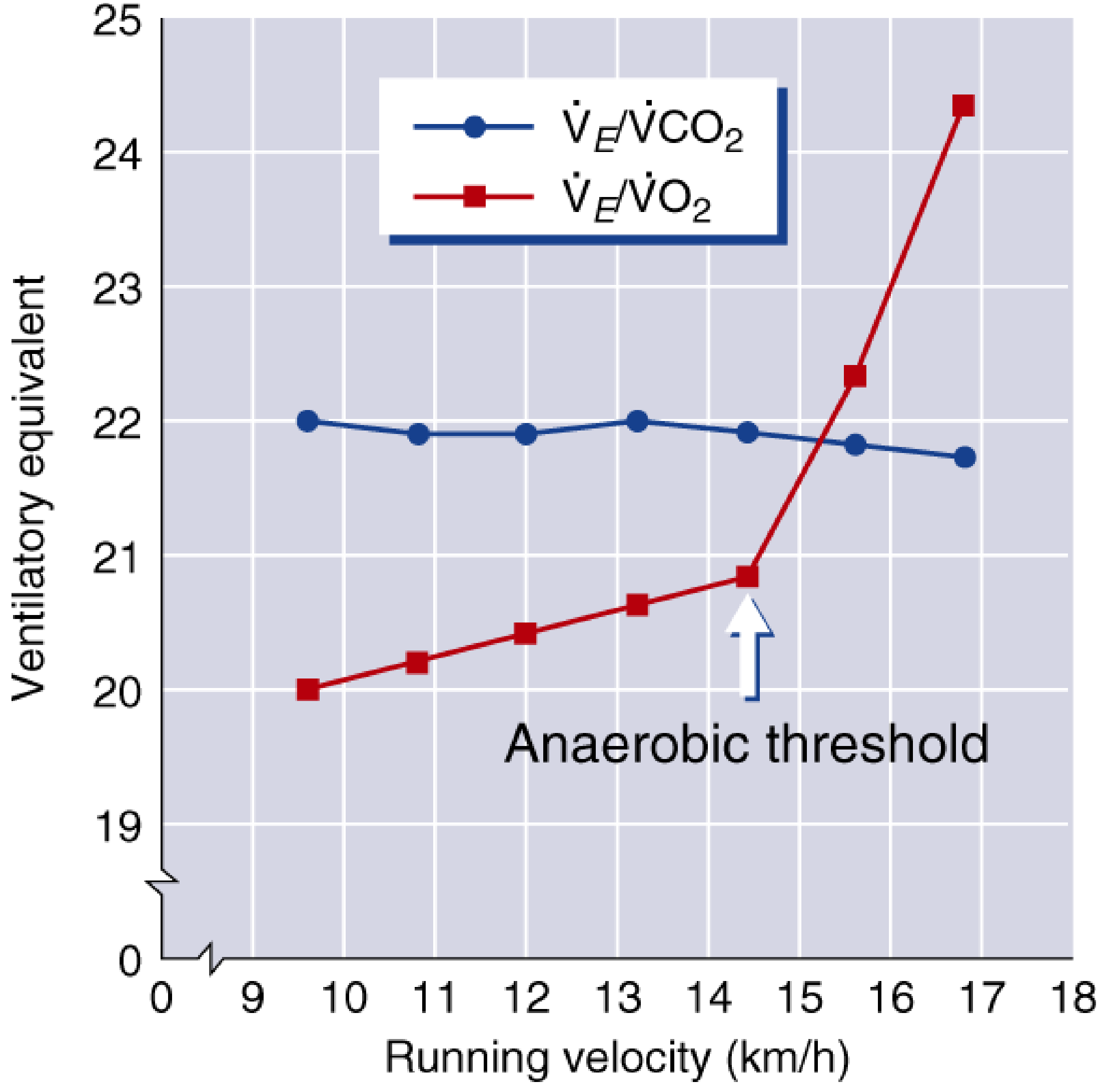
Running speed (km/h)	$\dot{V}_E/\dot{V}O_2$
9.6	21.5
10.8	20.0
12.0	20.4
13.2	20.3
14.4	24.9
15.6	33.3



Anaerobic Threshold

- Point during intense exercise at which metabolism becomes increasingly more anaerobic
- Reflects the lactate threshold under most conditions, though the relationship is not always exact
- Identified by noting an increase in $\dot{V}_E/\dot{V}O_2$ without an concomitant increase in the ventilatory equivalent for carbon dioxide ($\dot{V}_E/\dot{V}CO_2$)

$\dot{V}_E/\dot{V}CO_2$ AND $\dot{V}_E/\dot{V}O_2$



Key Points

Pulmonary Ventilation

- The respiratory centers in the brain stem set the rate and depth of breathing.
- Chemoreceptors respond to increases in CO_2 and H^+ concentrations or to decreases in blood oxygen levels by increasing respiration.
- Ventilation increases at the initiation of exercise due to inspiratory stimulation from muscle activity. As exercise progresses, increase in muscle temperature and chemical changes in the arterial blood further increase ventilation.

(continued)

Key Points

Pulmonary Ventilation

- Unusual breathing patterns associated with exercise include dyspnea, hyperventilation, and the Valsalva maneuver.
- During mild, steady-state exercise, ventilation parallels oxygen uptake.
- The ventilatory breakpoint is the point at which ventilation increases disproportionately to the increase in oxygen consumption.
- Anaerobic threshold is identified as the point at which $\dot{V}_E/\dot{V}O_2$ shows a sudden increase, while $\dot{V}_E/\dot{V}CO_2$ stays stable. It generally reflects lactate threshold.

Respiratory Limitations to Performance

- Respiratory muscles may use up to 11% of total oxygen consumed during heavy exercise and seem to be more resistant to fatigue during long-term activity than muscles of the extremities.
- Pulmonary ventilation is usually not a limiting factor for performance, even during maximal effort, though it can limit performance in highly trained people.
- Airway resistance and gas diffusion usually do not limit performance in normal healthy individuals, but abnormal or obstructive respiratory disorders can limit performance.

Key Points

Respiratory Adaptations to Training

- Pulmonary ventilation increases during maximal effort after training; you can improve performance by training the inspiratory muscles.
- Pulmonary diffusion increases at maximal work rates.
- The a-$\bar{v}O_2$ diff increases with training due to more oxygen being extracted by tissues.
- The respiratory system is seldom a limiter of endurance performance.
- All the major adaptations of the respiratory system to training are most apparent during maximal exercise.

VO_2 Adaptations to Training

Oxygen consumption ($\dot{V}O_2$) is

- unaltered or slightly increased at rest,
- unaltered or slighted decreased at submaximal rates of work, and
- increased at maximal exertion ($\dot{V}O_2max$—increases range from 0% to 93%).

Factors Affecting $\dot{V}O_2max$

Level of conditioning—the greater the level of conditioning the lower the response to training

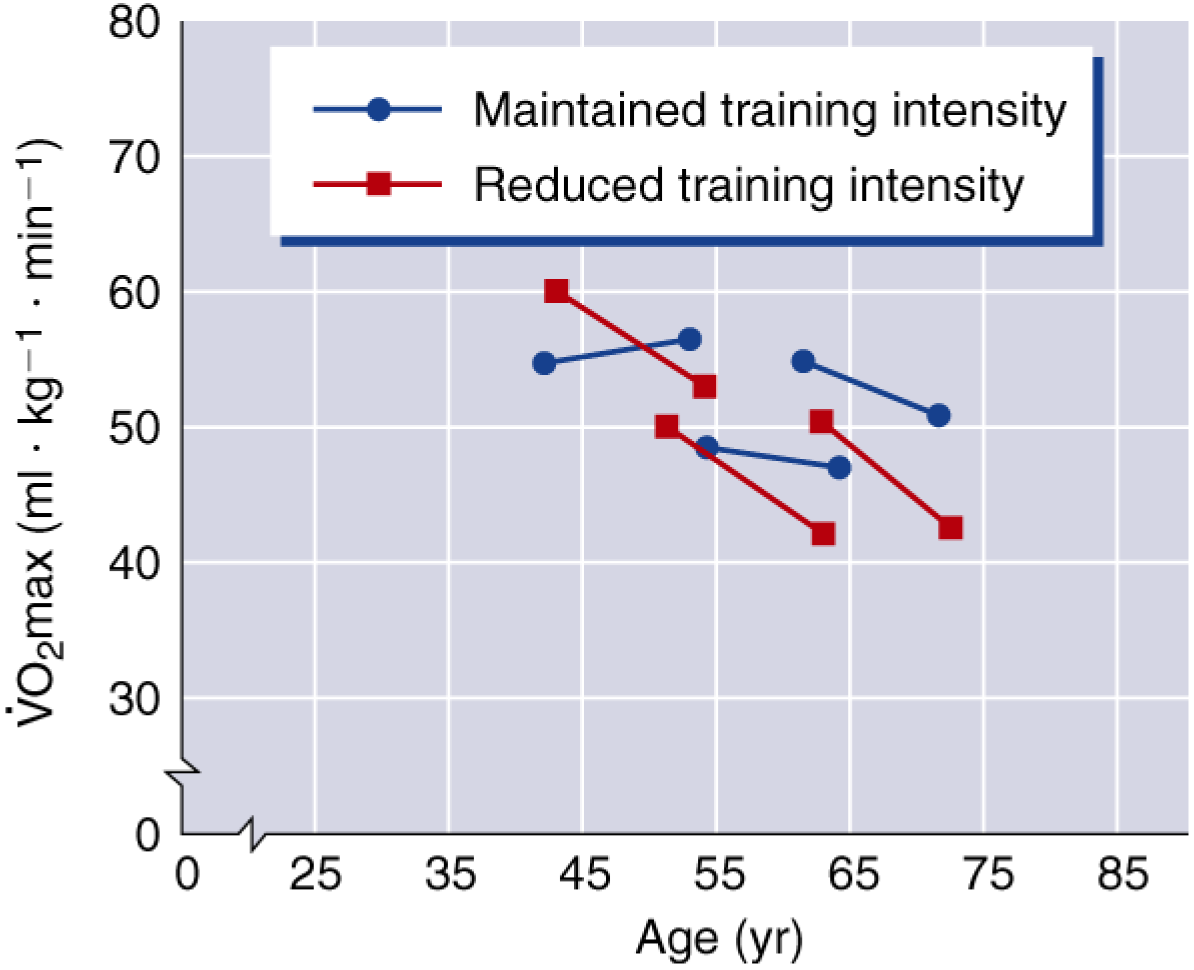
Heredity—accounts for slightly less than 50% of the variation as well as an individual’s response to training

Age—decreases with age are associated with decreases in activity levels as well as decreases in physiological function

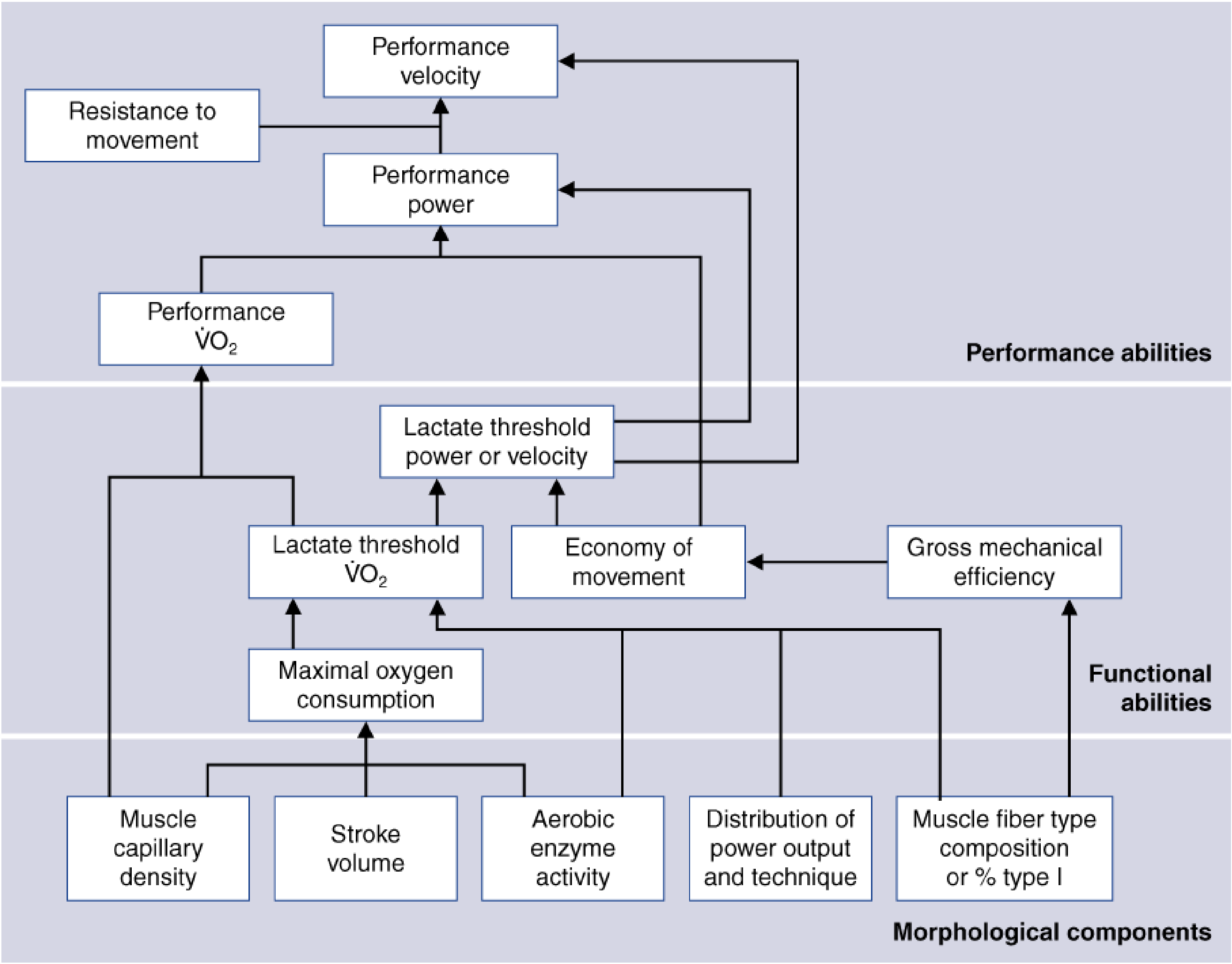
Sex—lower in women than men (20% to 25% lower in untrained women; 10% lower in highly trained women)

Specificity of training—the closer training is to the sport to be performed, the greater the improvement and performance in that sport

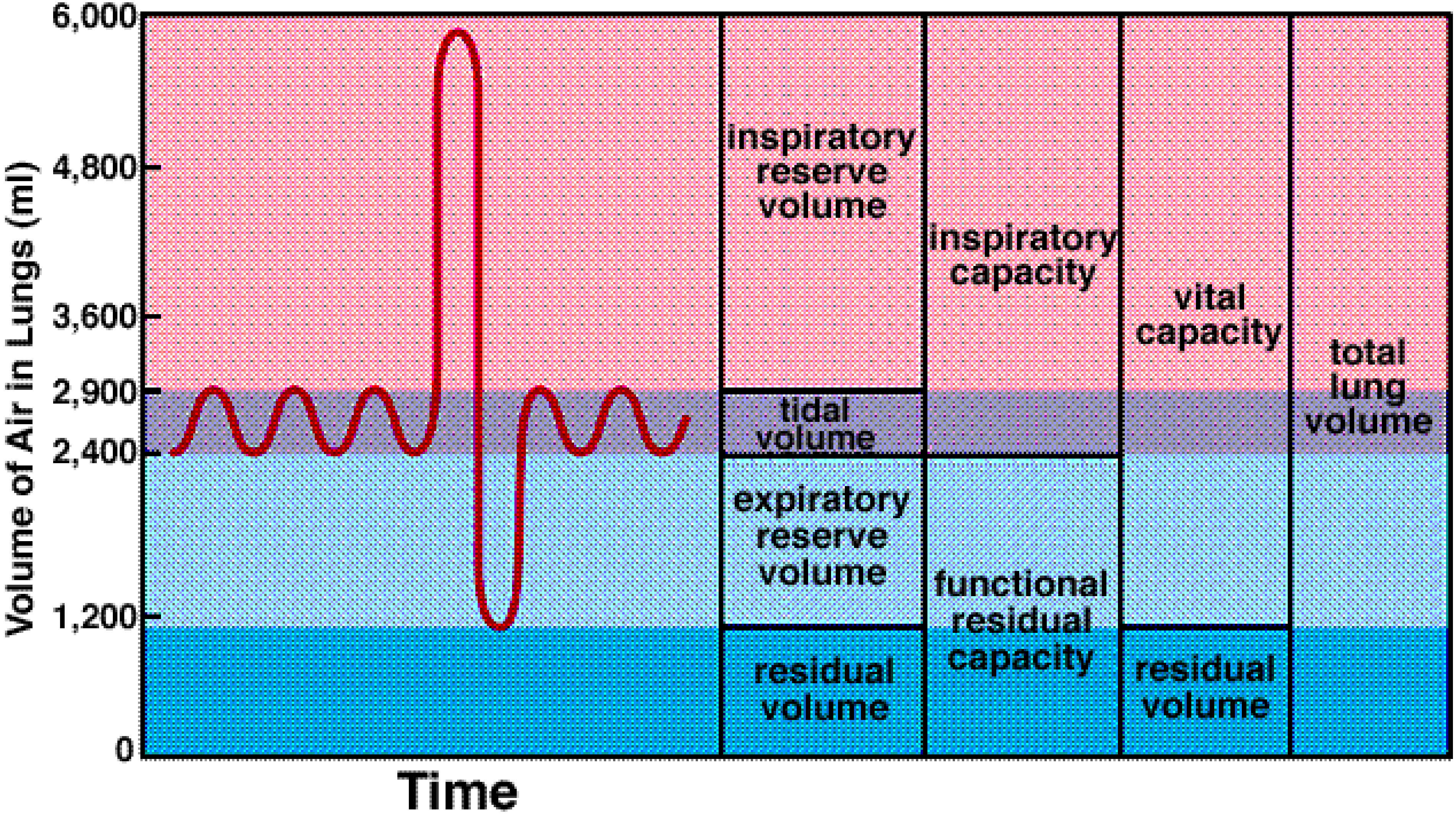
$\dot{V}O_2$MAX CHANGES AND AGE



MODELING ENDURANCE PERFORMANCE



Measuring Vital Capacity



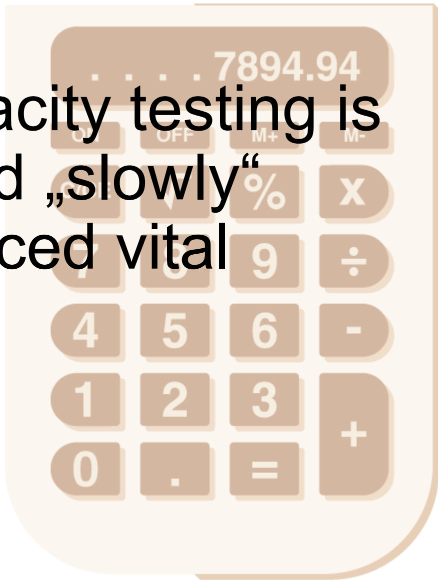
Vital capacity

Vital capacity is the maximum amount of air that can be forcefully expired after a maximum inspiration.

VC females = 3-4 l

VC males = 4-5.5 l

From the pulmonary function test the vital capacity testing is the most frequently used. It could be performed „slowly“ (VC) and/or as fast and forced as possible (forced vital capacity, FVC)



Vital capacity - procedure

Calcultae your predicted value of the vital capacity:

Males:

Predict. VC (ml) = [27.63 – (0.112 x age (yrs)] x height (cm)

Females:

Predict. VC (ml) = [21.78 – (0.101 x age (yrs)] x height (cm)

Compare your measured values with the predicted values and express them as a percentage of the predicted values.

BTPS

All the pulmonary volumes should be standardiesd, i.e. converted from actual conditions (ATPS) to the BTPS conditions (Body Temperature and atmospheric Pressure completly Saturated with water vapour at body temperature).

BTPS for Czech Republic is 1.09