Cardiovascular system

Cardiovascular control during exercise

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Cardiovascular system

1. Functions
2. Heart and cardiovascular system
   a) Anatomy
   b) Heart rate
   c) Cardiac cycle
   d) Intrinsic conduction system
   e) ECG
   f) Blood pressure
   g) Blood distribution
3. Cardiovascular system and exercise
   a) Useful terms
   b) Responses vs adaptations
   c) Parameters
4. Blood
   a) Hematocrit, viscosity
   b) Functions
   c) Hemoglobin

1. Cardiovascular system and its functions

- A pump – the heart 
- A system of channels – the blood vessels 
- A fluid medium – blood 

What are the roles of the heart and the vessels?

1. Cardiovascular system and its functions

A. Delivery (e.g., oxygen and nutrients)

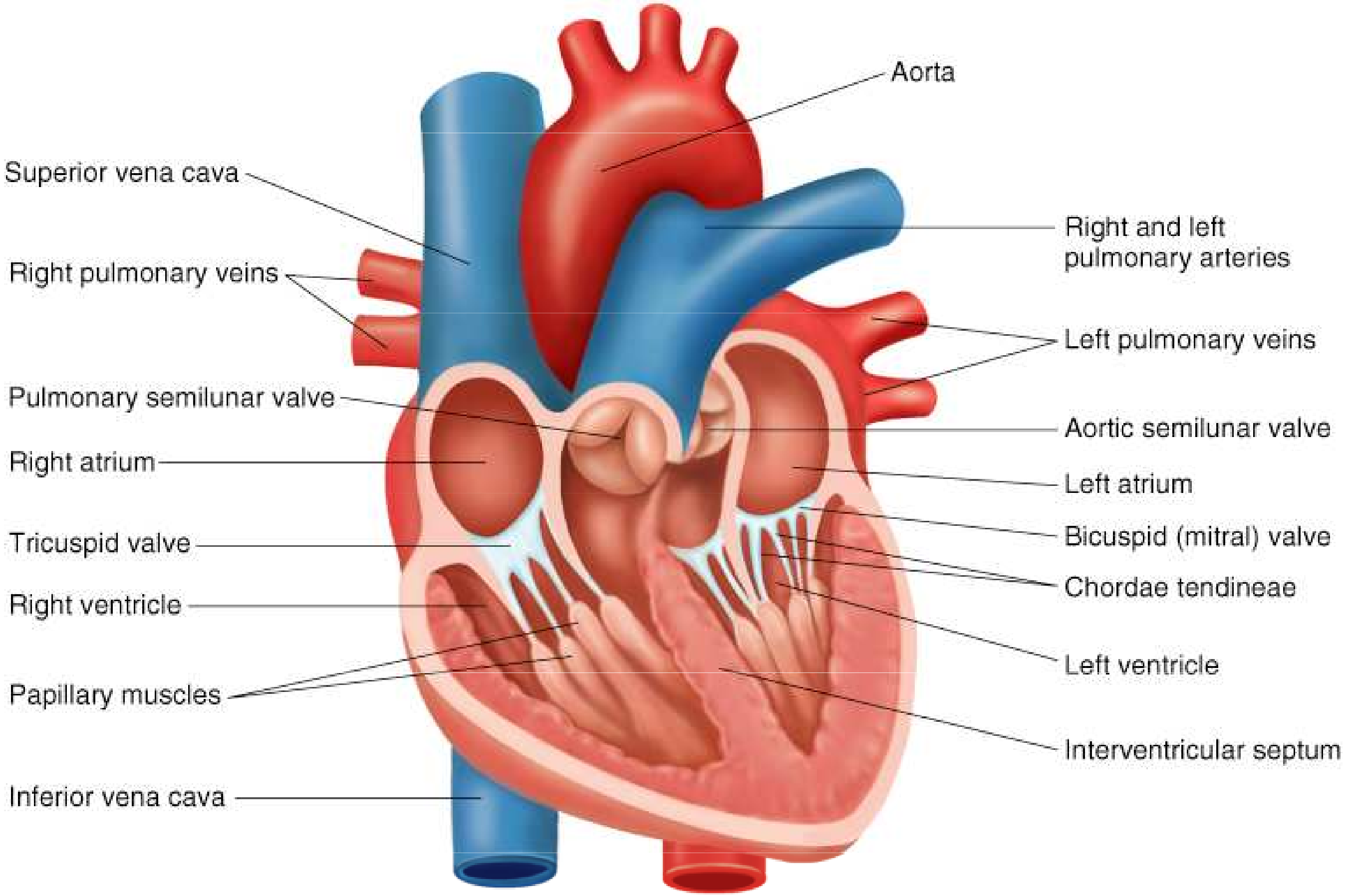
B. Removal (e.g., carbon dioxide, lactate, other waste products)

C. Transportation (e.g., hormones)

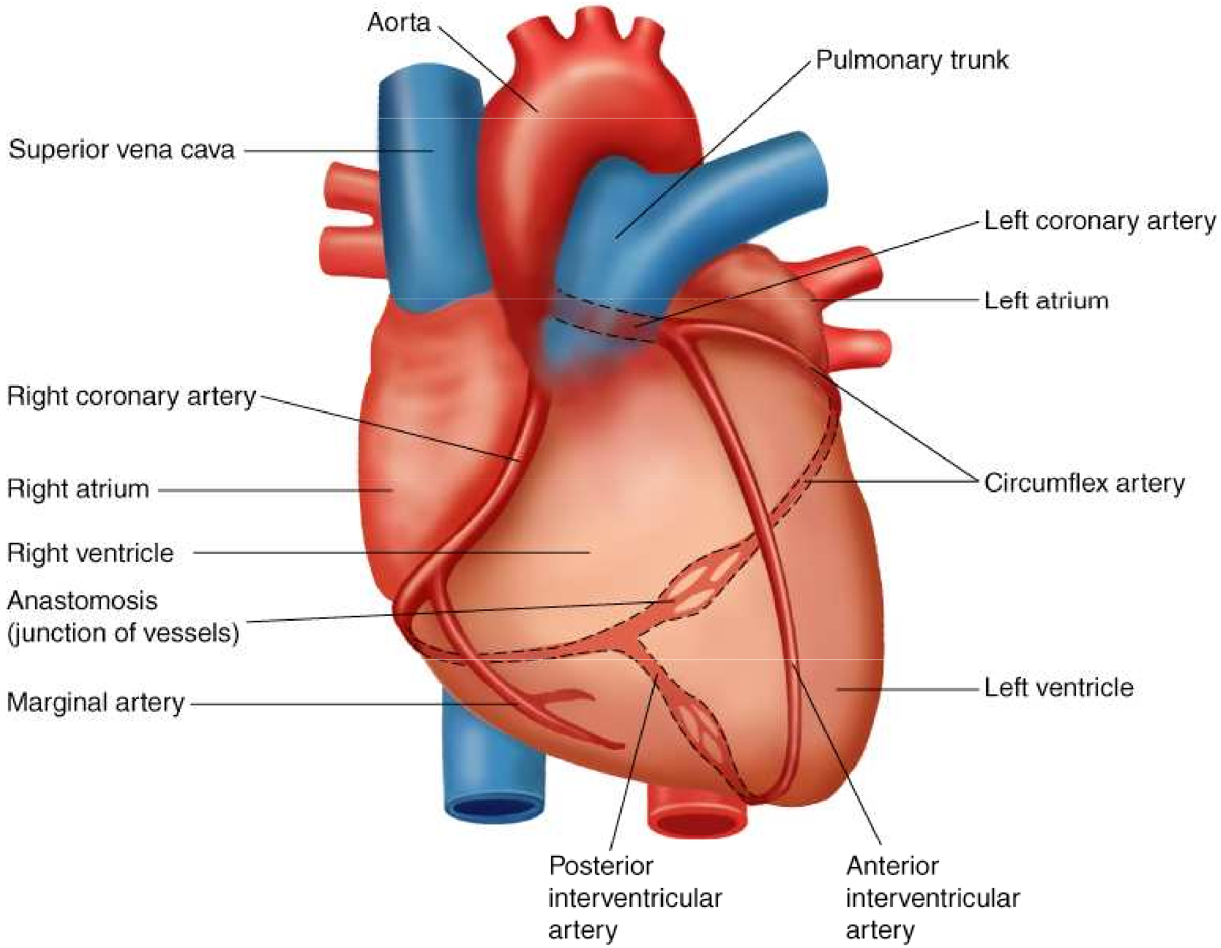
D. Maintenance (e.g., body temperature, pH)

E. Prevention (e.g., infection—immune function)

2a) Heart anatomy



2a) Heart anatomy



Key points

- The two atria receive blood into the heart; the two ventricles send blood from the heart to the rest of the body.

- The left ventricle has a thicker myocardium due to hypertrophy resulting from the resistance against which it must contract.

2b) Heart Rate

What is the average resting heart rate frequency?

2b) Heart Rate

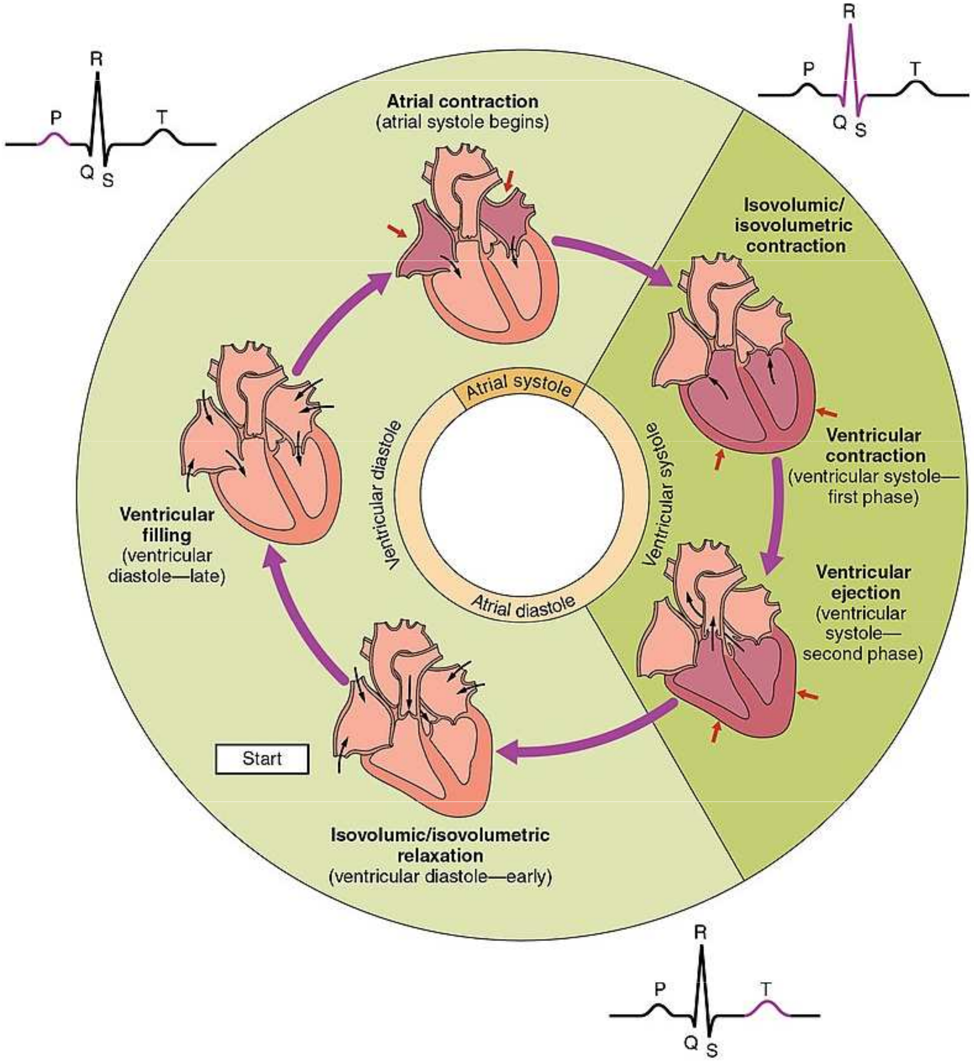
- **Resting heart rates** in adults tend to be between 60 and 80 beats/min. However, extended endurance training can lower resting heart rate to **40 beats/min or less.** This lower heart rate is thought to be due to decreased intrinsic heart rate and increased parasympathetic stimulation.

2b) Cardiac Arrhythmias

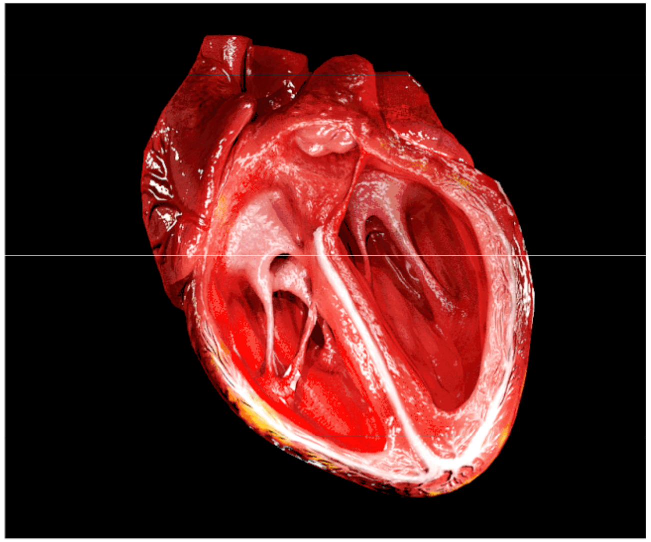
- BRADYCARDIA – Resting heart rate **below 60 beats/min**
- TACHYCARDIA – Resting heart rate **above 100 beats/min**
- PREMATURE VENTRICULAR CONTRACTIONS (PVCs) – feels like skipped or extra beats
- VENTRICULAR TACHYCARDIA – three or more consecutive **PVCs** that can lead to **ventricular fibrillation** in which contraction of the ventricular tissue is uncoordinated

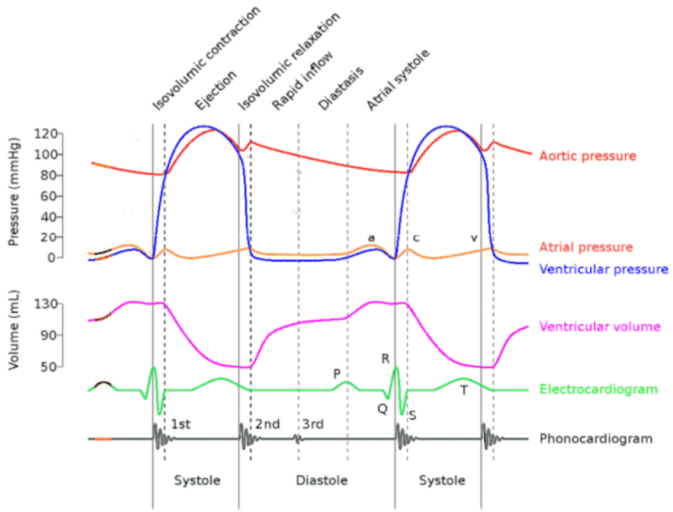
2c) Cardiac cycle

- The event that occurs between two consecutive heartbeats (systole to systole)
- Diastole — relaxation phase during which the chambers fill with blood — 62% of cycle duration
- Systole — contraction phase during which the chambers expel blood — 38% of cycle duration

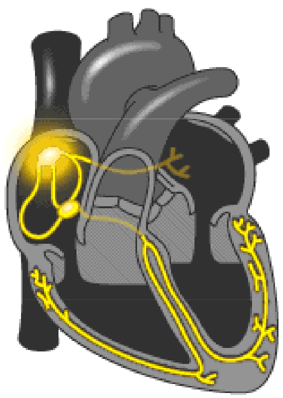


Cardiac Cycle



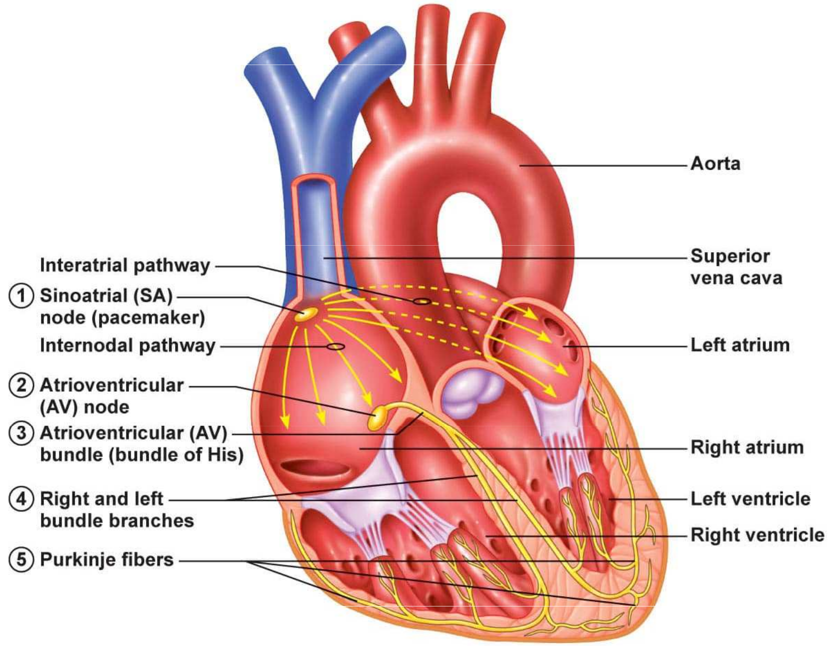


2d) Intrinsic Conduction System



2d) Intrinsic Conduction System

- Cells of Intrinsic conduction system (ICS) generate their own electrical impulses
- Sinoatrial node (SA node) – the pacemaker
  - it generates electrical impulses the fastest and sets the rhythm for the rest of ICS; heavily controlled
- Atrioventricular node (AV node)
- AV bundle
- Bundle branches
- Purkinje fibers (subendocardial conducting network) – contractions of the ventricles



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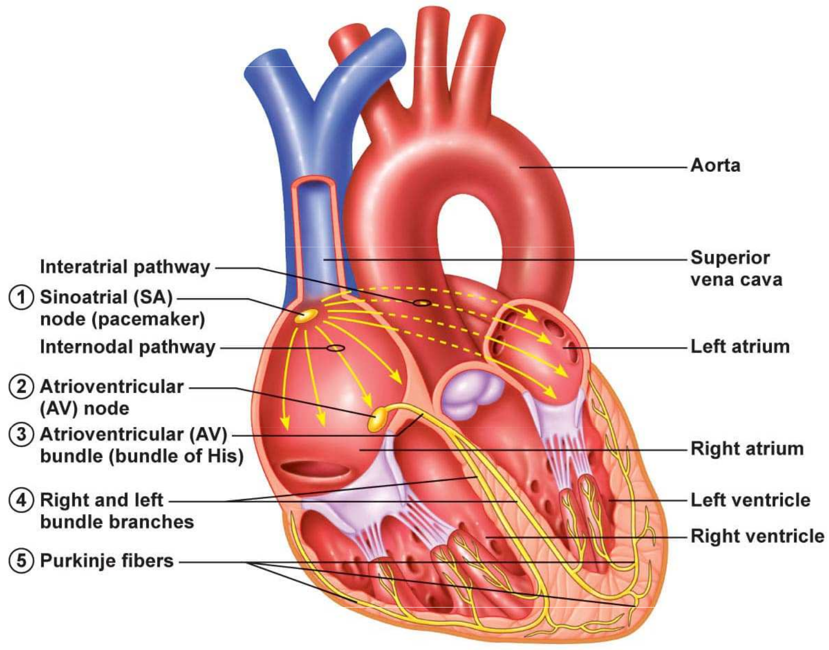
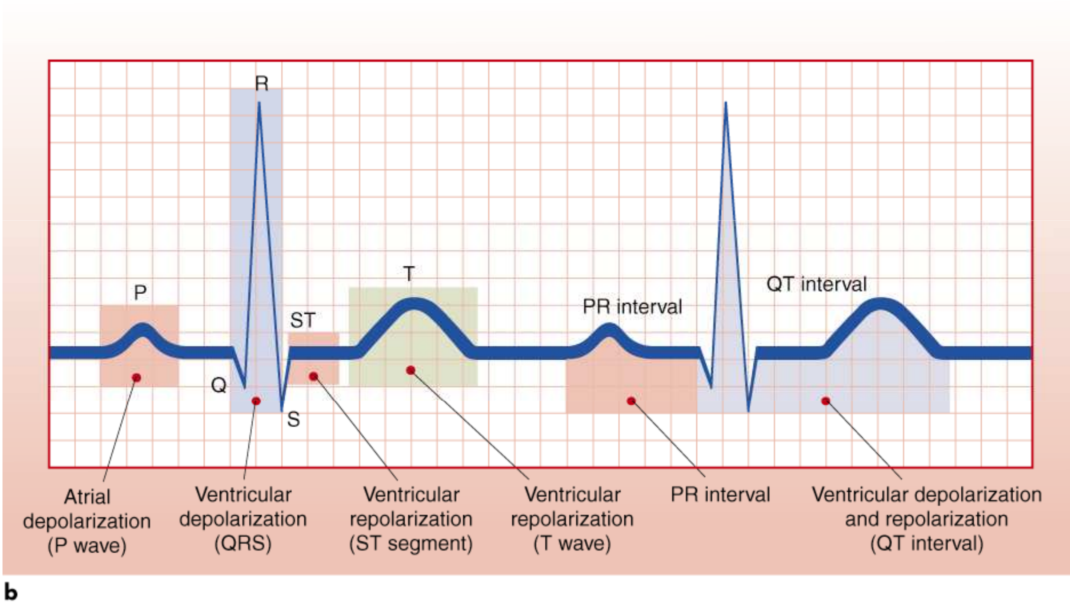


2e) Electrocardiogram (ECG)

- Printout shows the heart's electrical activity – can be used to monitor cardiac changes
- The P wave – atrial depolarization
- The QRS complex – ventricular depolarization and atrial repolarization
- ST segment – plateau of action potential, ventricles pump blood
- The T wave – ventricular repolarization (diastole)

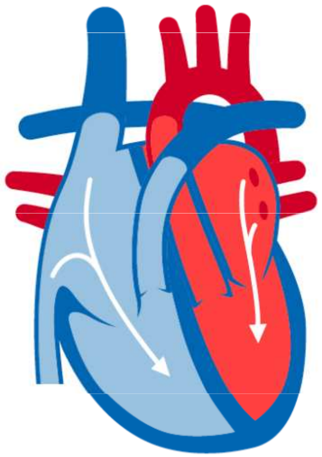


2f) Blood pressure

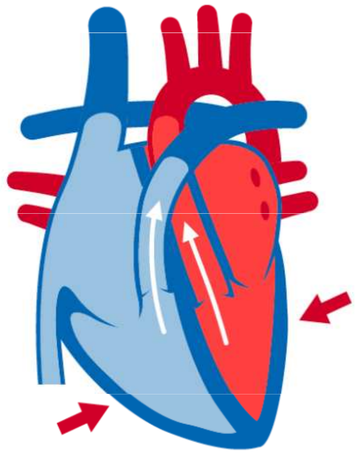
- Systolic blood pressure (**SBP**) is the highest pressure and diastolic blood pressure (**DBP**) is the lowest pressure
- Mean arterial pressure (**MAP**) — average pressure exerted by the blood as it travels through arteries
- MAP = DBP + [0.333 ´ (SBP – DBP)]

- Rest Blood Pressure is about 120/80

- Hypertension: BP = more than 140/90
- Hypotension: BP = less than 90/60



Diastolic Blood Pressure

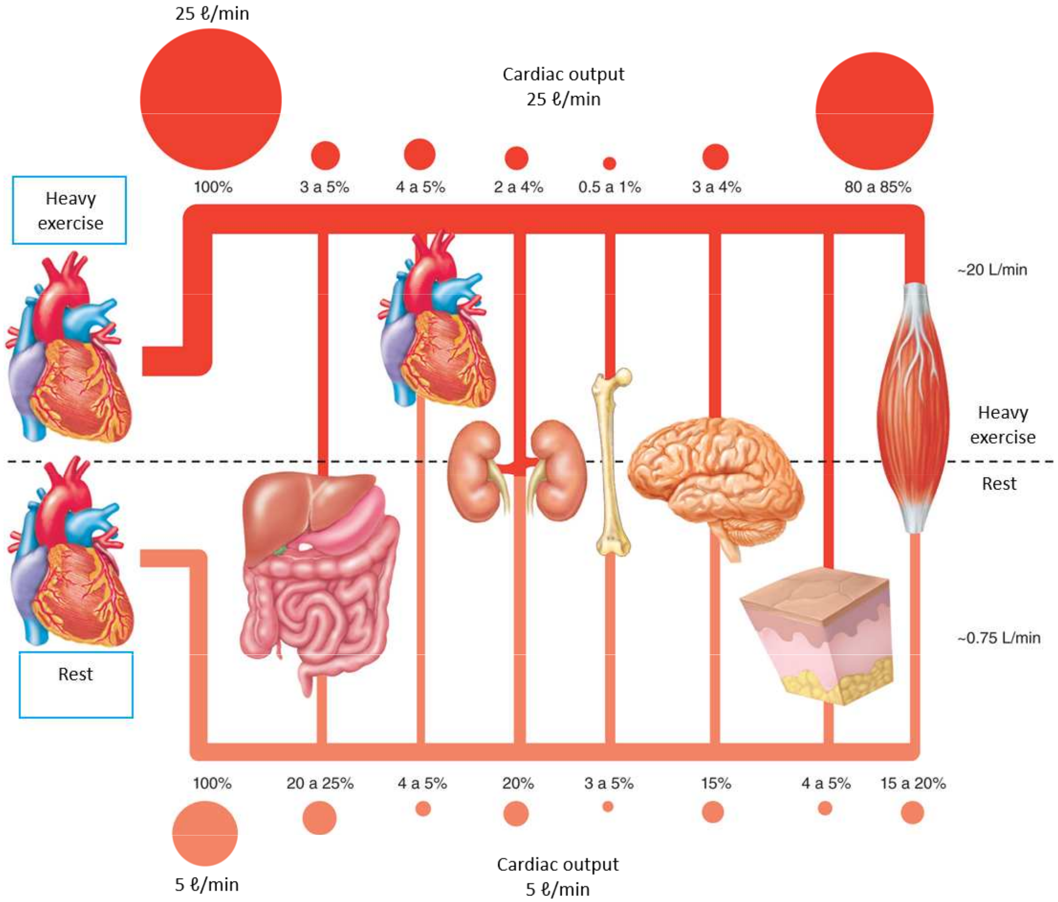


Systolic Blood Pressure

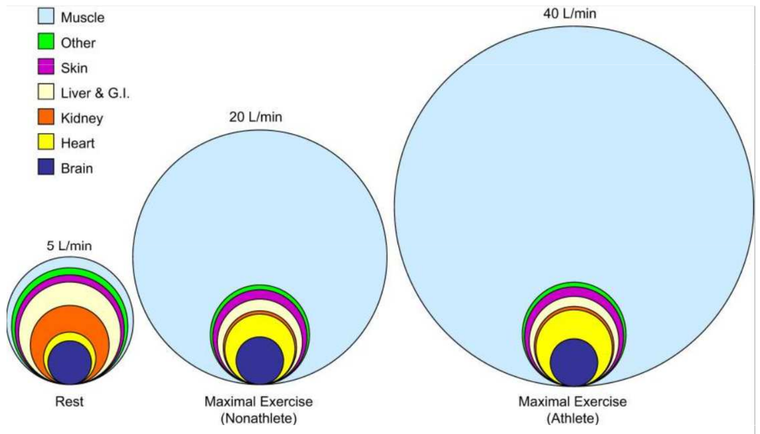
BLOOD PRESSURE GUIDELINES

Blood Pressure Category	Systolic (mmHg)		Diastolic (mmHg)
NORMAL	<120	&	<80
ELEVATED	120 – 129	&	<80
HYPERTENSION STAGE 1	130 – 139	or	80 – 89
HYPERTENSION STAGE 2	140+	or	90+
HYPERTENSIVE CRISIS	180+	&/or	120+

2g) Blood distribution



Fuente: Stuart Ira Fox: *Fisiología humana*, 14e: www.accessmedicina.com



Total blood flow and its distribution during rest and brief exercise requiring VO_2 max

3a) Cardiovascular system and exercise

TERMS:

- Heart rate (HR)
  - RHR = resting heart rate
  - HRmax
- Blood pressure (BP)
  - RBP = resting blood pressure
- Stroke volume (SV) = volume of blood pumped per contraction
- Cardiac output (Q) is the total volume of blood pumped by the ventricles per minute
  - Q=HRxSV
- VO_2 max
- Extraction of oxygen a-vO_2 difference
  - Difference between the oxygen content in arterial and mixed-venous blood
  - a-vO2 diff = Ca – Cv

3a) Cardiovascular system and exercise

- Stroke volume (SV)
  - 50-100 ml on average
  - End-Diastolic Volume (EDV) – blood volume in a ventricle before contraction
  - End-Systolic Volume (ESV) – blood volume in a ventricle after contraction
  - SV = EDV – ESV

3b) Cardiovascular system and exercise

a) Response vs b) Adaptation

a) Response

- Acute (short-term)
- Physiology
- Function

b) Adaptation

- Chronic (long-term)
- Anatomy
- Structure

3b) Cardiovascular Response to Acute Exercise

Anticipation of exercise:

- **Heart rate increases**
- **Adrenalin** is released

3b) Cardiovascular Response to Acute Exercise

During exercise:

- Heart rate (HR) increases as exercise intensity increases up to maximal heart rate
- Stroke volume (SV) increases up to 40% to 60% VO_2max in untrained individuals and up to maximal levels in trained individuals.
- Increases in HR and SV during exercise cause cardiac output (Q) to increase
- Blood flow and SBP (systolic blood pressure) increase
- All result in allowing the body to efficiently meet the increased demands placed on it
- Redirection of blood flow – vasoconstriction and vasodilation

3b) Cardiovascular Adaptations to Training

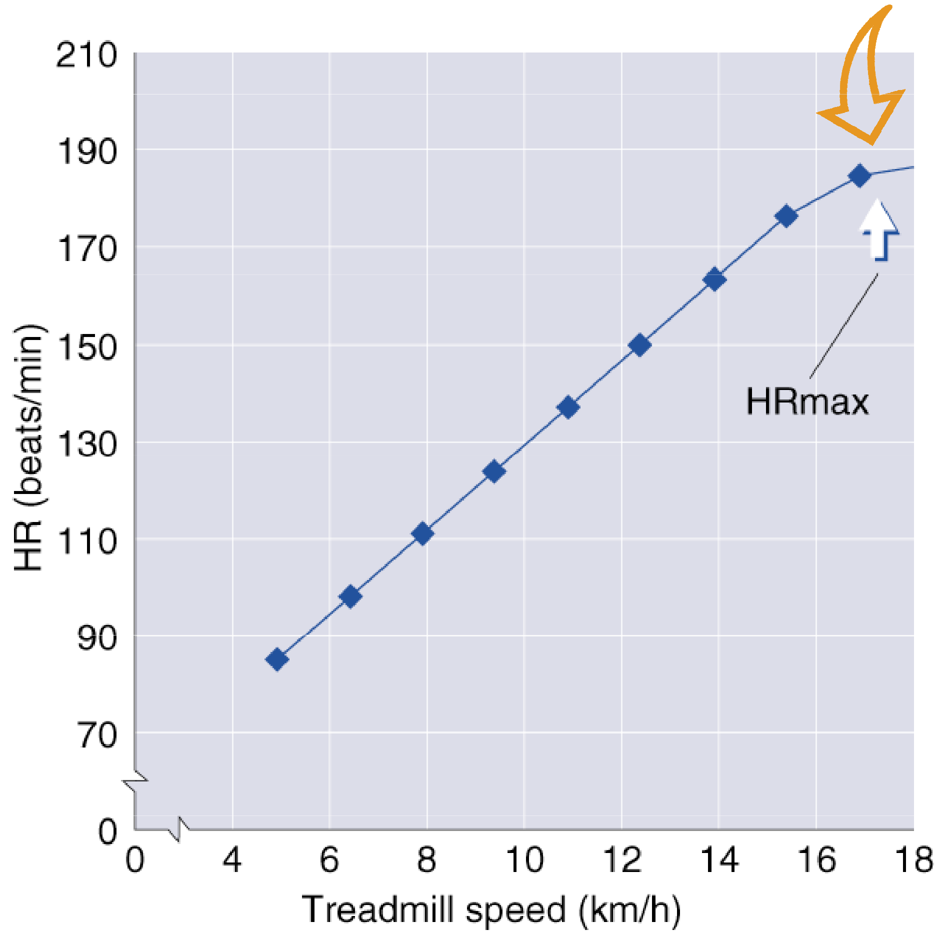
- Left ventricle size and wall thickness increase
- Resting, submaximal, and maximal stroke volume increases
- Maximal heart rate stays the same or decreases
- Resting heart rate decreases
- Cardiac output is better distributed to active muscles and maximal cardiac output increases
- Blood volume increases, as does red cell volume but to a lesser extent
- Resting blood pressure does not change or decreases slightly, while blood pressure during submaximal exercise decreases

3c) Resting and Maximum Heart Rate

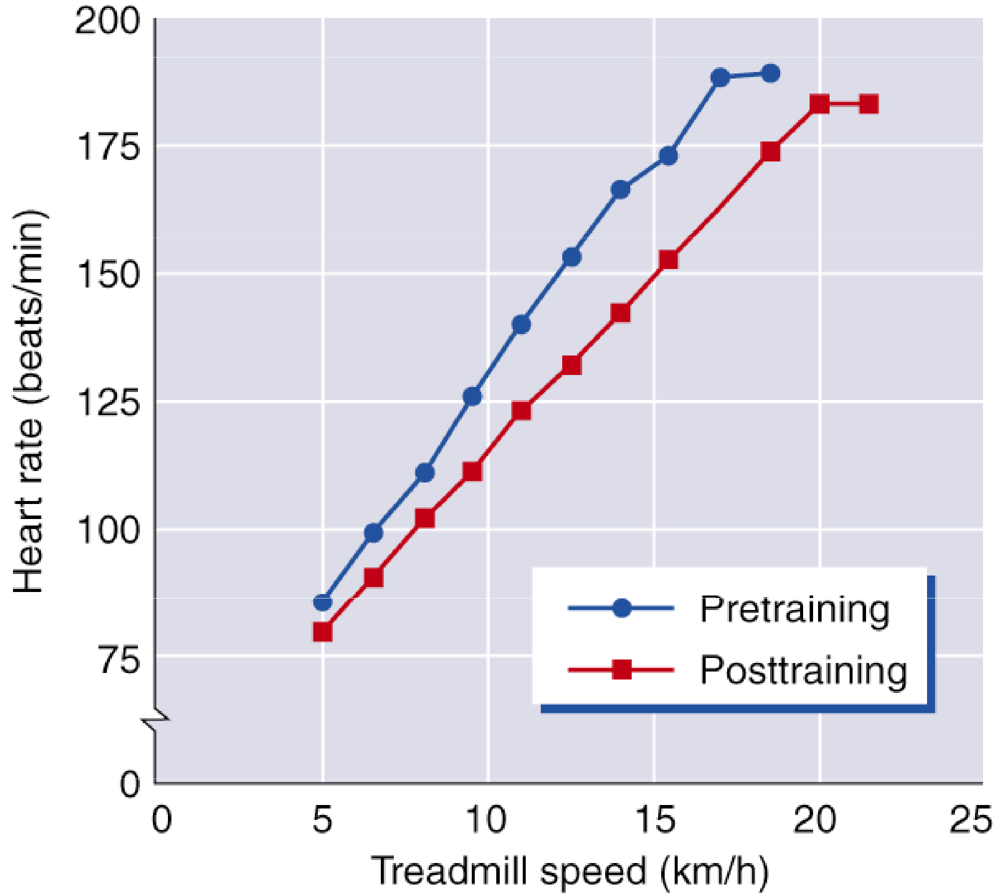
- RHR
- Averages 60 to 80 beats/min; can range from 28 to above 100 beats/min
- Tends to decrease with age and with increased cardiovascular fitness
- Is affected by environmental conditions such as altitude and temperature

- HRmax
- The highest heart rate value one can achieve in an all-out effort to the point of exhaustion
- Remains constant day to day and changes slightly from year to year
- Can be estimated:
  - HRmax = 220 – age in years or
  - HRmax = 208 – (0.7 x age)

3c) Heart Rate and Intensity



3c) Heart Rate and Training



3c) Resting Heart Rate

- **Decreases with endurance training** likely due to more blood returning to heart and changes in autonomic control
- Sedentary individuals can decrease RHR by 1 beat/min per week during initial training, but several recent studies have shown small changes of less than 3 beats/min with up to 20 wk of training
- Highly trained endurance athletes may have resting heart rates of **30 to 40 beats/min**

3c) Heart Rate During Exercise

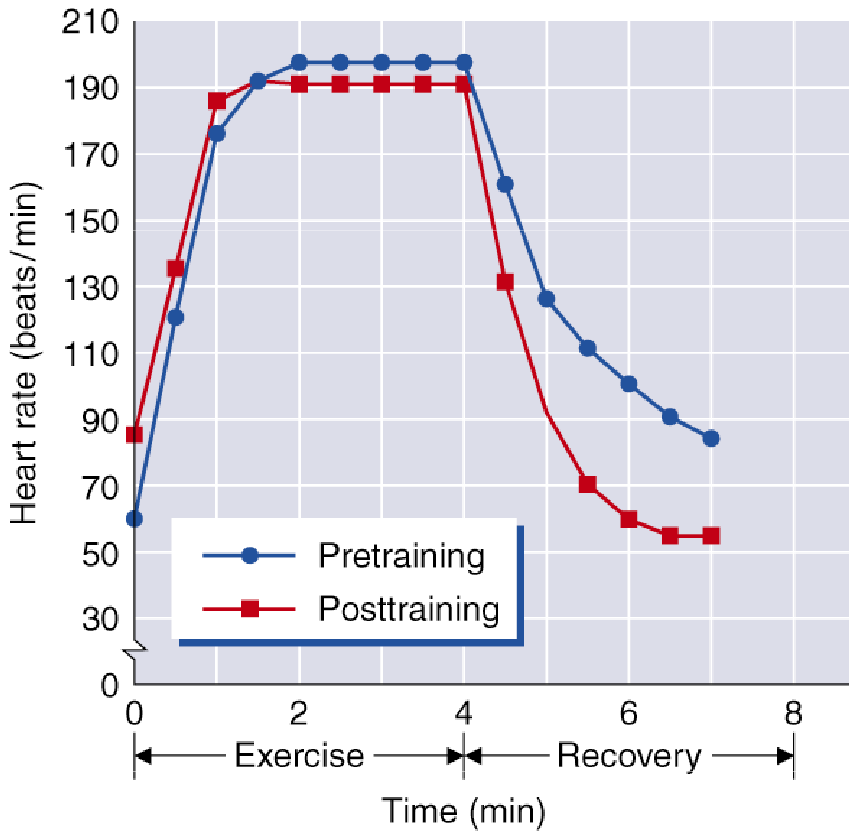
- SUBMAXIMAL
  - Decreases proportionately with the amount of training completed
  - May decrease by 10 to 30 beats/min after 6 months of moderate training at any given rate of work, with the decrease being greater at higher rates of work

- MAXIMAL
  - Remains unchanged or decreases slightly
  - A decrease might allow for optimal stroke volume to maximize cardiac output

3c) Heart Rate Recovery Period

- The time after exercise that it takes your heart to return to its resting rate
- With training, heart rate returns to resting level more quickly after exercise
- Has been used as an index of cardiorespiratory fitness
- Conditions such as altitude or heat can affect it
- Should not be used to compare individuals to one another

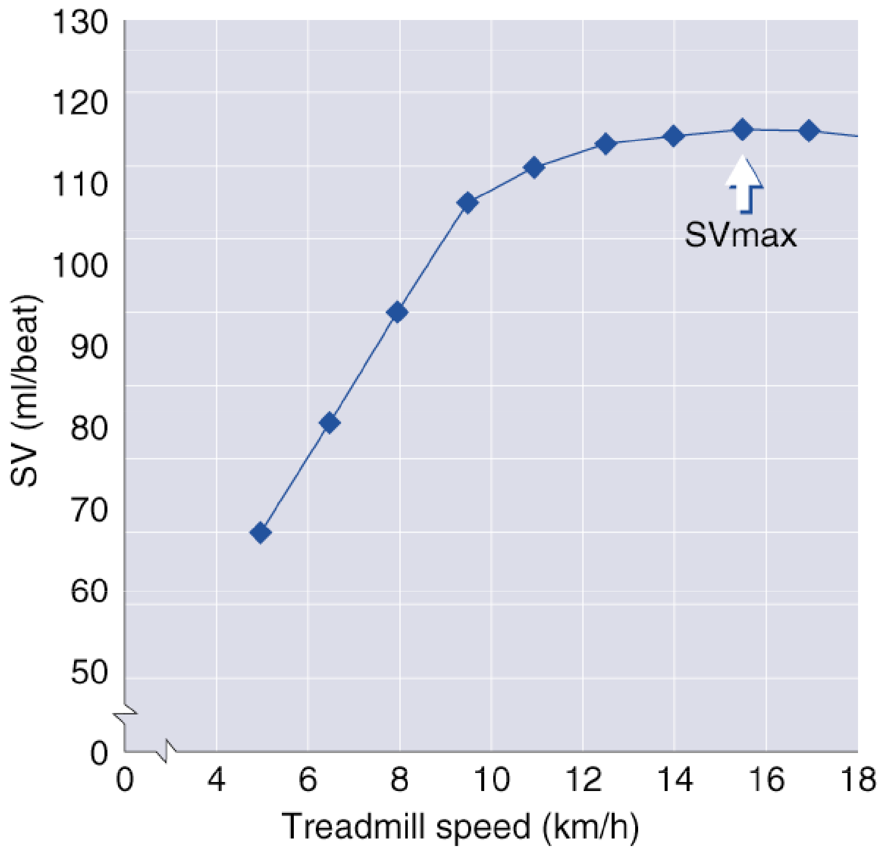
3c) Heart Rate Recovery Period and Training



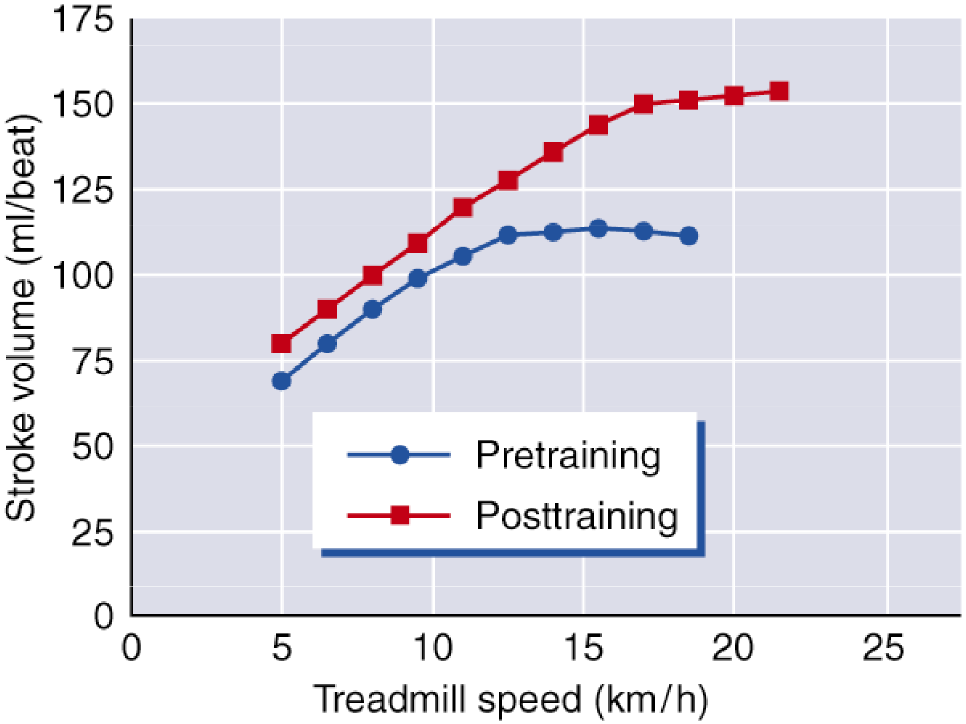
3c) Stroke Volume

- Determinant of cardiorespiratory endurance capacity at maximal rates of work
- Increases with increasing rates of work up to intensities of 40% to 60% of max or higher
- May continue to increase up through maximal exercise intensity, generally in highly trained athletes
- Magnitude of changes in SV depends on position of body during exercise

3c) Stroke Volume and Intensity



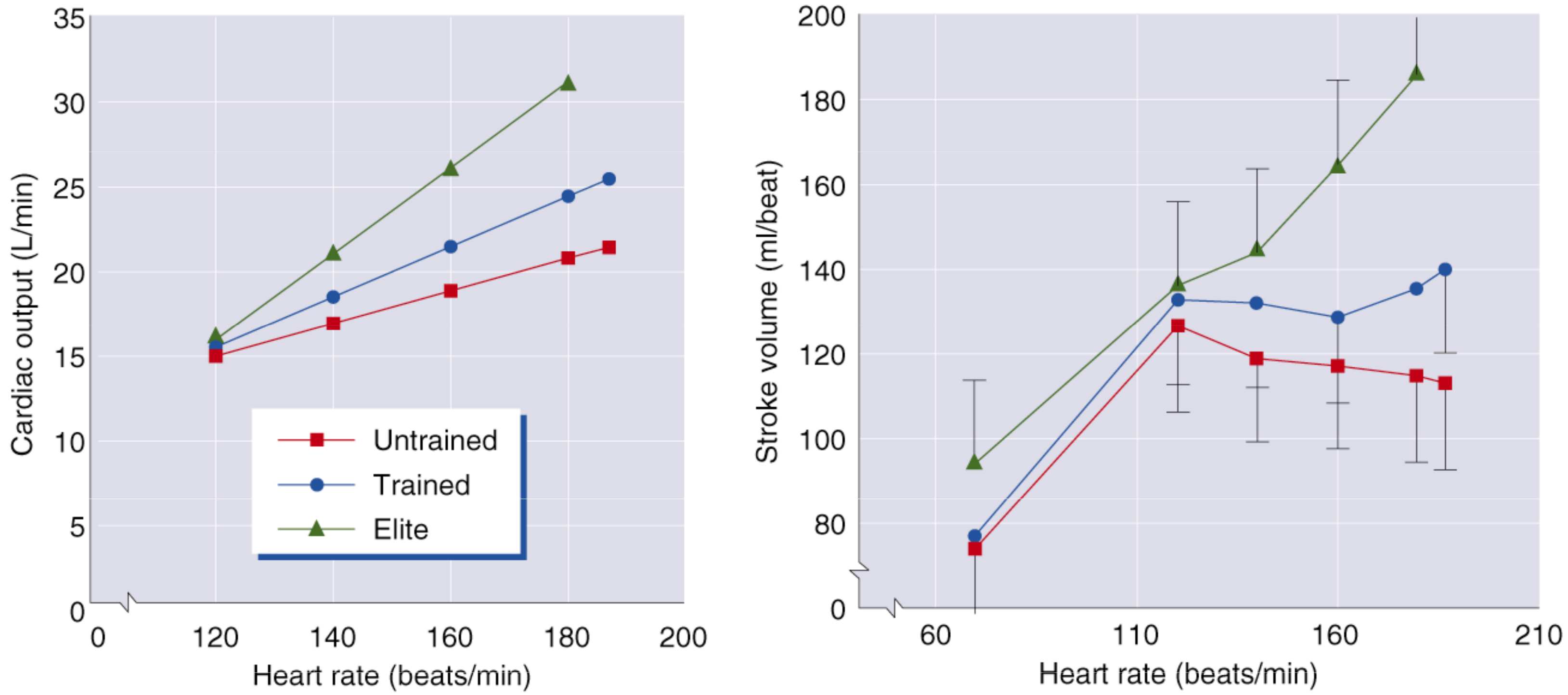
3c) Stroke Volume and Training



Stroke Volumes (SV) for Different States of Training

Subjects	SVrest (ml)	SVmax (ml)
Untrained	50-70	80-110
Trained	70-90	110-150
Highly trained	90-110	150-220

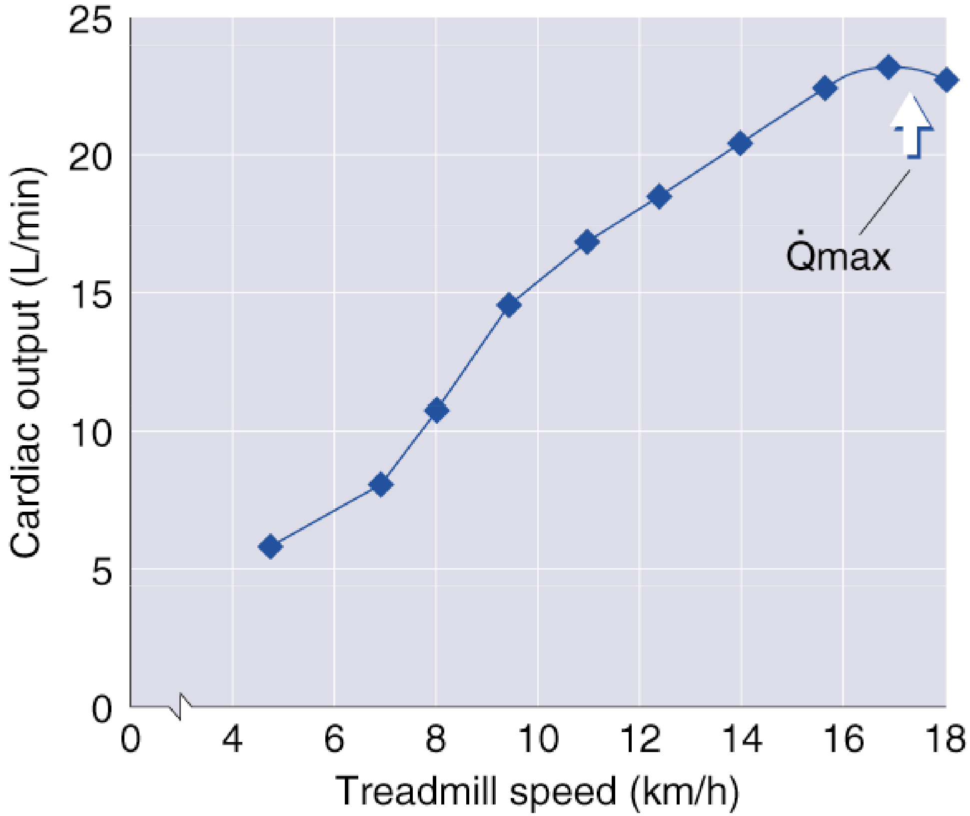
3c) Changes in Q and SV with Increasing Rates of Work



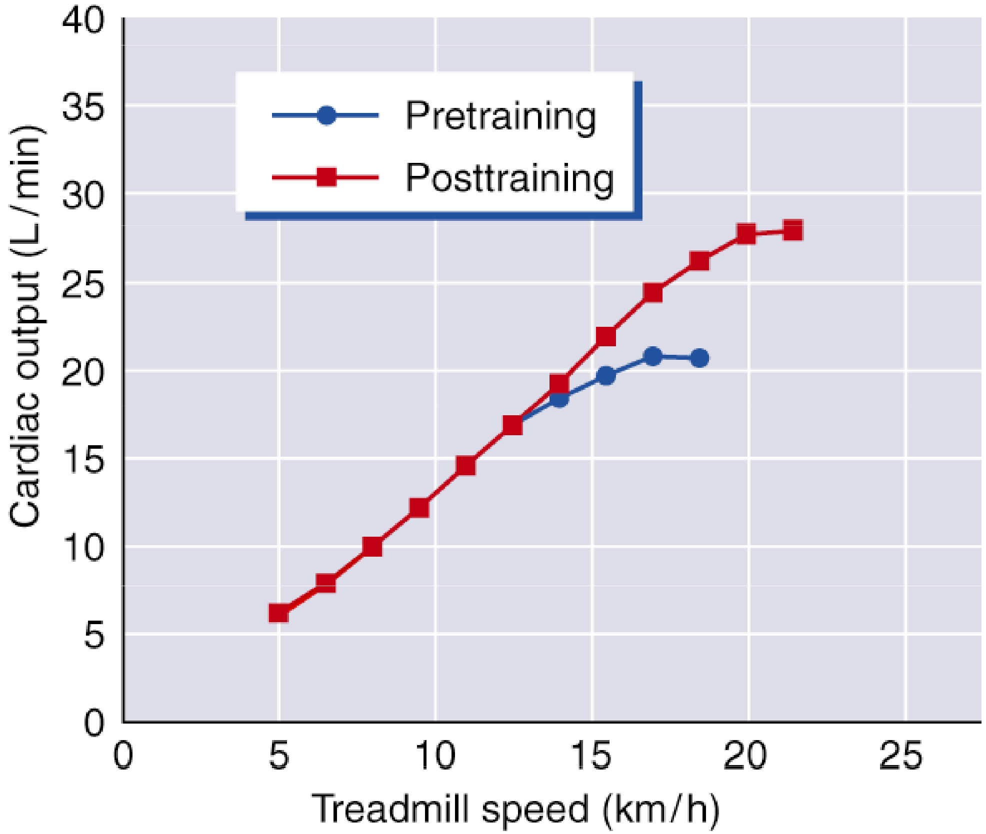
3c) Cardiac Output

- Resting value is approximately 5.0 L/min.
- Increases directly with increasing exercise intensity to maximal values of between 20 to 40 L/min.
- The magnitude of increase varies with body size and endurance conditioning.
- When exercise intensity exceeds 40% to 60%, further increases in Q are more a result of increases in HR than SV since SV tends to plateau at higher work rates.

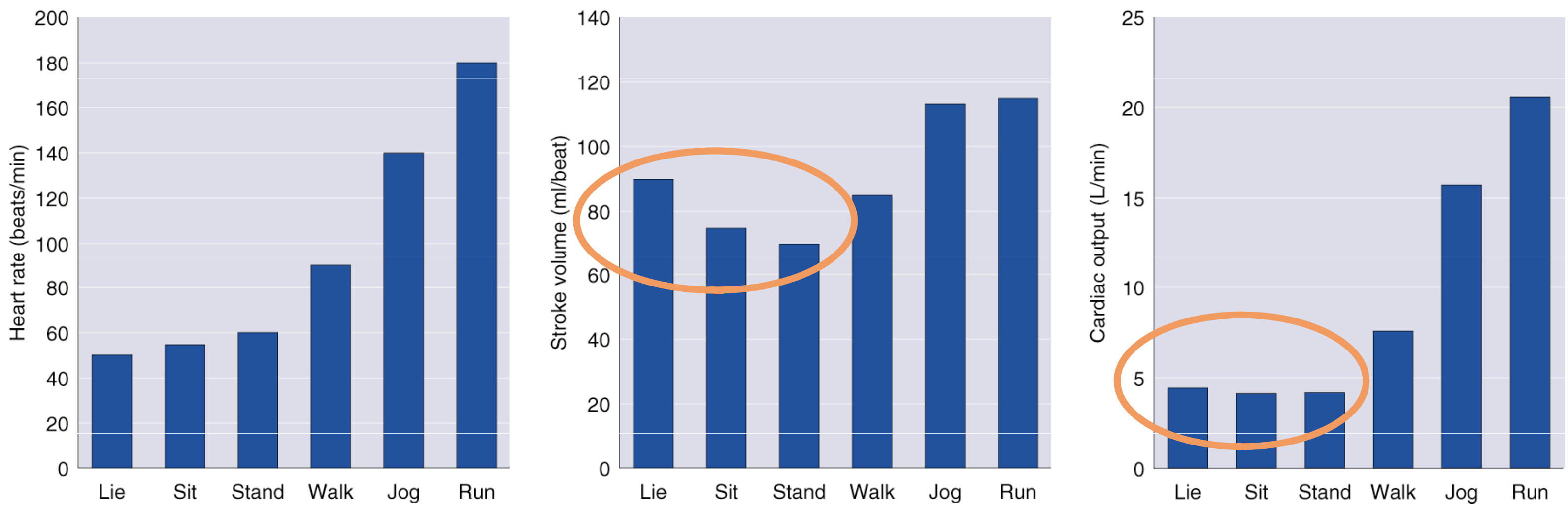
3c) Cardiac Output and Intensity



3c) Cardiac Output and Training



3c) Changes in HR, SV, and Q with Changes in Position and Exercise Intensity



3c) Blood Pressure

- Cardiovascular Endurance Exercise
  - Systolic BP increases in direct proportion to increased exercise intensity
  - Diastolic BP changes little if any during endurance exercise, regardless of intensity
- Resistance Exercise
  - Exaggerates BP responses to as high as 480/350 mmHg

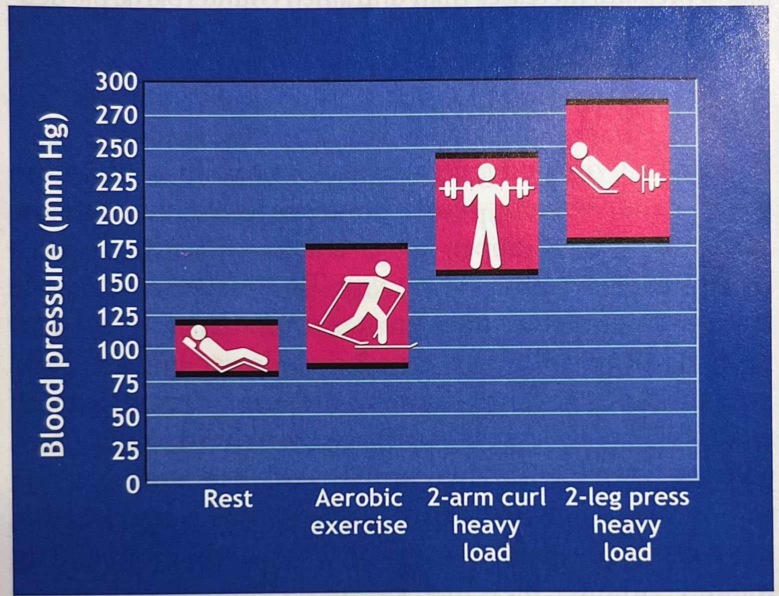
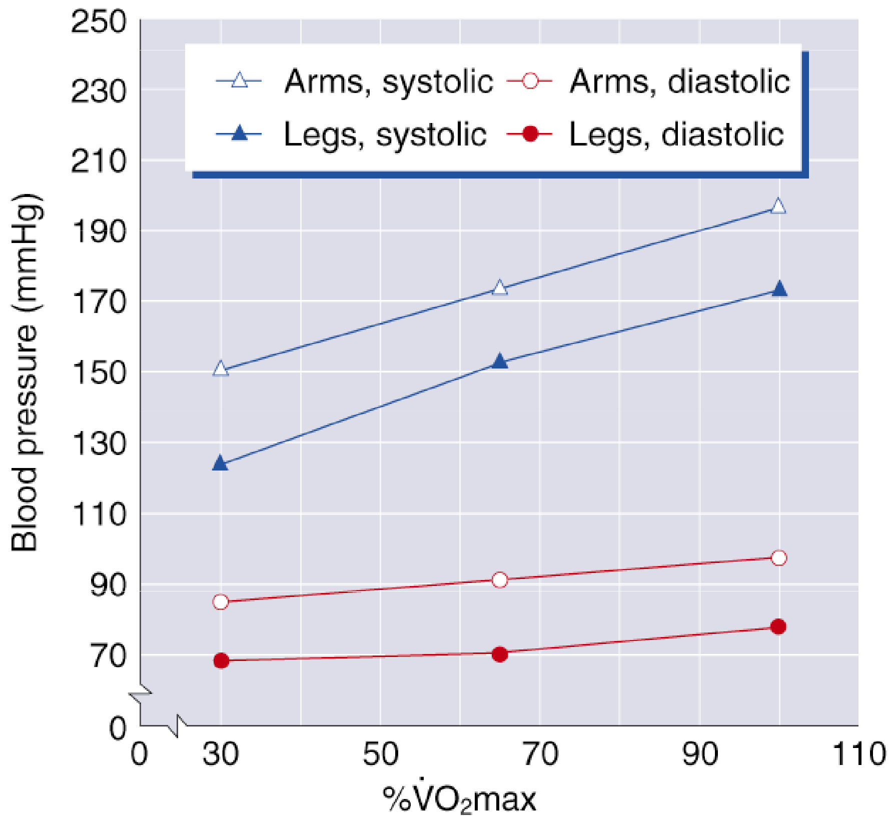
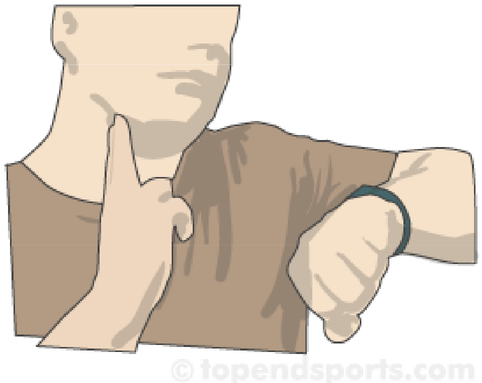


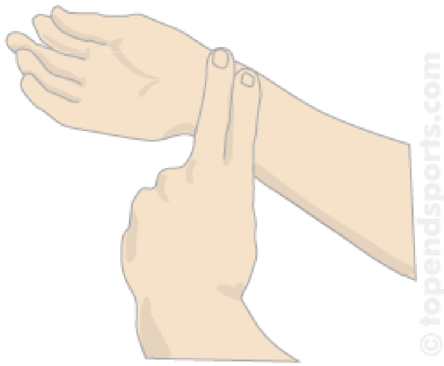
FIGURE 10.7 Heavy-resistance exercise magnifies the exercise blood pressure response (higher with legs than arms) compared with rhythmic, continuous aerobic exercise. The height of the bar indicates pulse pressure. (Reprinted with permission from McArdle WD, Katch FI, Katch VL. *Exercise Physiology: Nutrition, Energy, and Human Performance*. 8th Ed. Baltimore: Wolters Kluwer Health, 2015.)

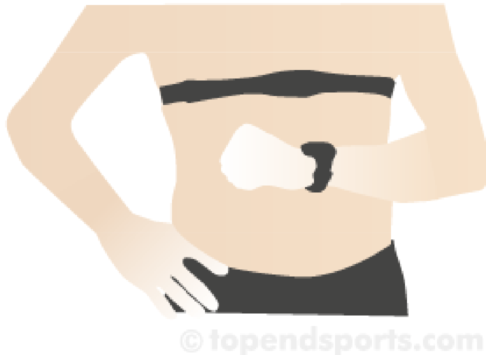
3c) Blood Pressure Responses



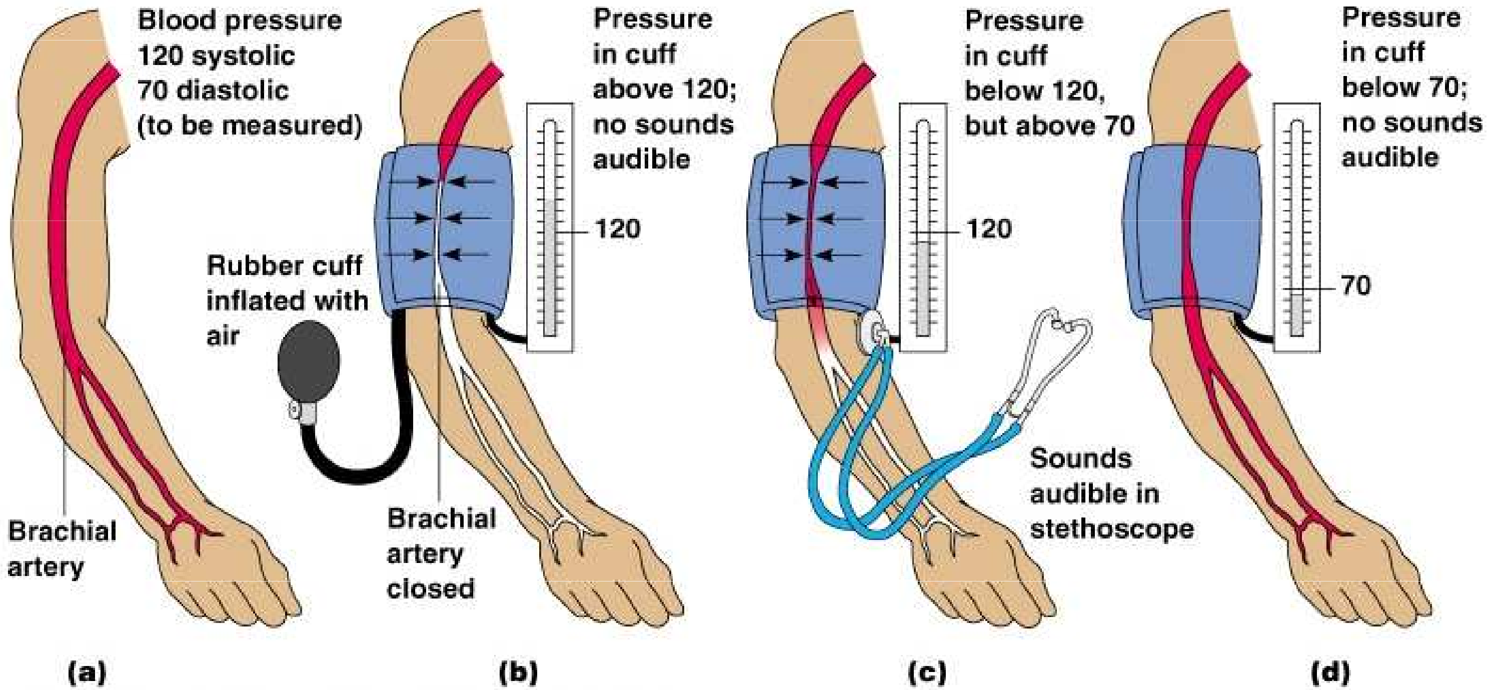
Heart rate measurements





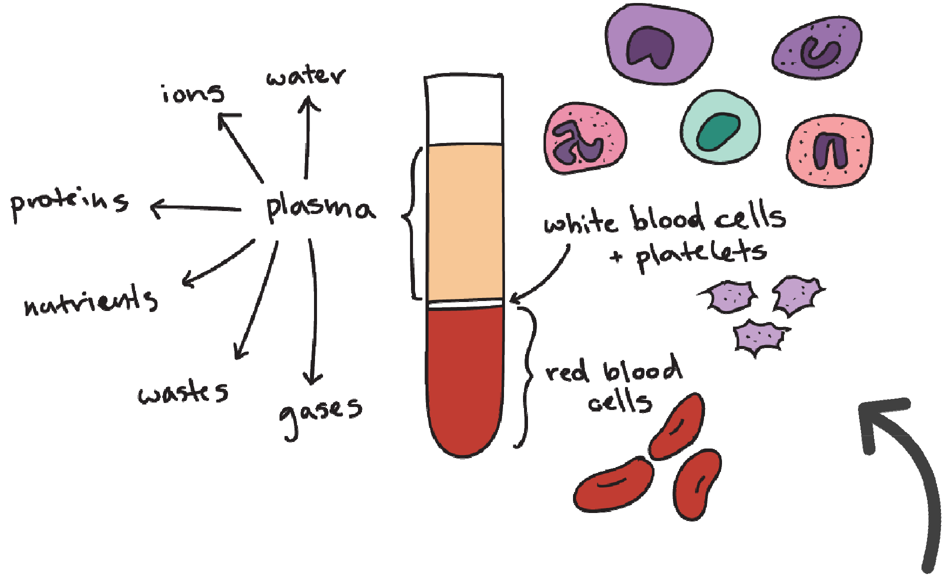


Blood pressure measurements



4. Blood

- **Connective tissue** (the only fluid tissue in the body)
- Accounts for approx. 7% of body weight
- An adult individual has approx. 5liters of blood
- Blood composition
  - Plasma (55%)
    - 91% water
    - 8% proteins – albumin, globulin (transportation)
    - 1% other molecules
  - Formed elements (45%)
    - 99% red blood cells (erythrocytes) – carry oxygen
    - <1% white blood cells (leukocytes) – protect from pathogens
  - Platelets (<1%)



Blood placed in a centrifuge

* Erythrocytes and platelets do not possess all the typical organelles and they can not divide – they are replaced by stem cells in the bone marrow

4a) Blood hematocrit, viscosity

$$* \, Hematocrit = \frac{Formed\ elements}{Total\ blood\ volume}$$

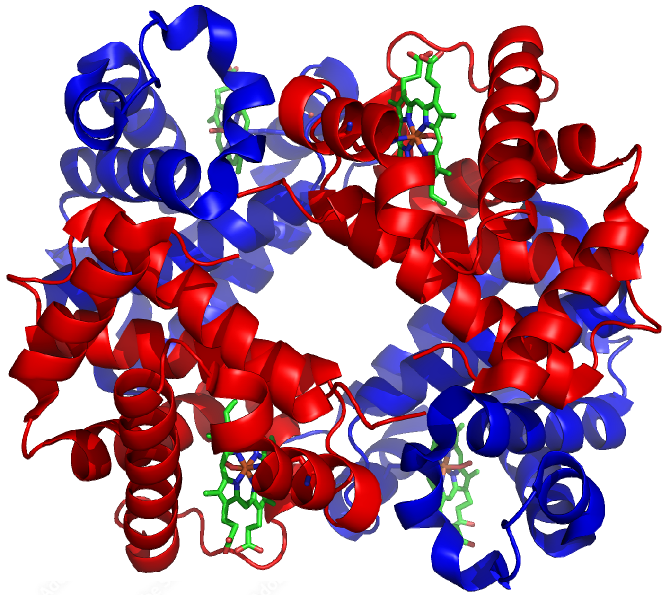
- Blood viscosity = thickness of the blood
- The more viscous, the more resistant to flow
- Higher hematocrits result in higher blood viscosity

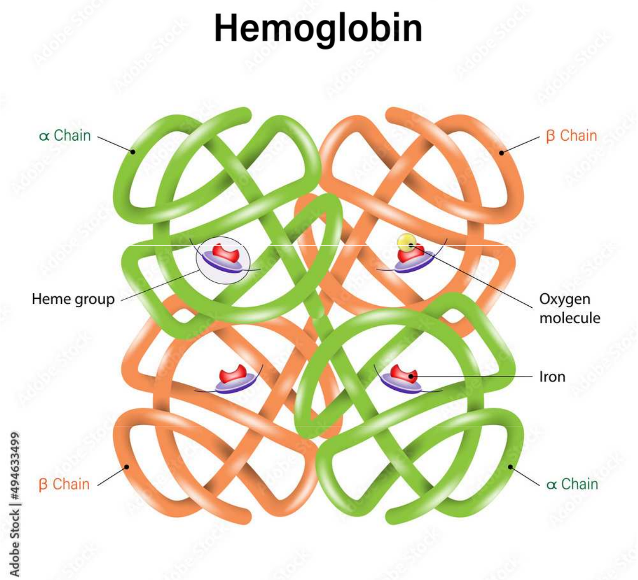
4b) Blood functions

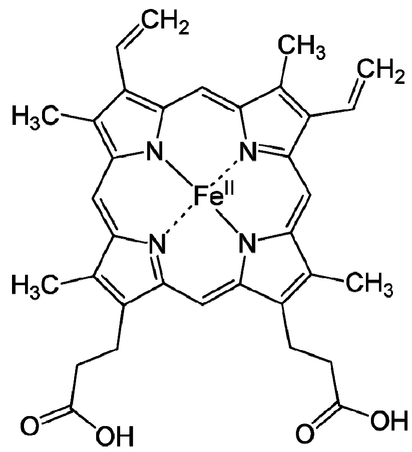
- Delivers oxygen to tissues
- Delivers nutrients such glucose, amino acids or fatty acids – dissolved in blood or attached to carrier proteins
- Transports waste products – CO_2, Urea, Lactic acid
- Transports hormones
- Protects from pathogens (Immunological functions) – white blood cells, Antibodies
- Regulates temperature
- Buffers and balances acid base homeostasis
- Coagulation (to stop bleeding)

4c) Hemoglobin (Hb)

- Hb comprises **4 globin** subunits – two α and two β units
- Each globin is attached to a **heme b group** with an **iron atom** at the center
- Each **heme b group** can carry one oxygen molecule attached to the iron atom
- Hb is present in two forms (influenced by partial pressures and pH)
  - Relaxed (R)
  - Tense (T)
  - Different absorption spectra - used for oxygen levels measurements



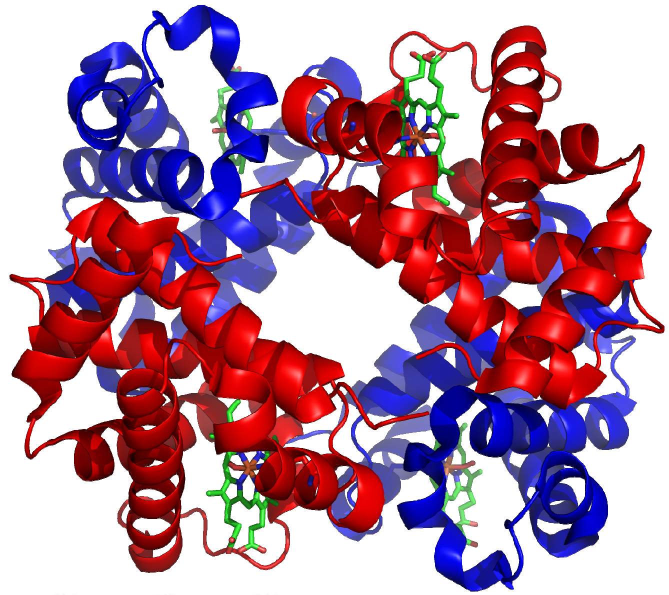


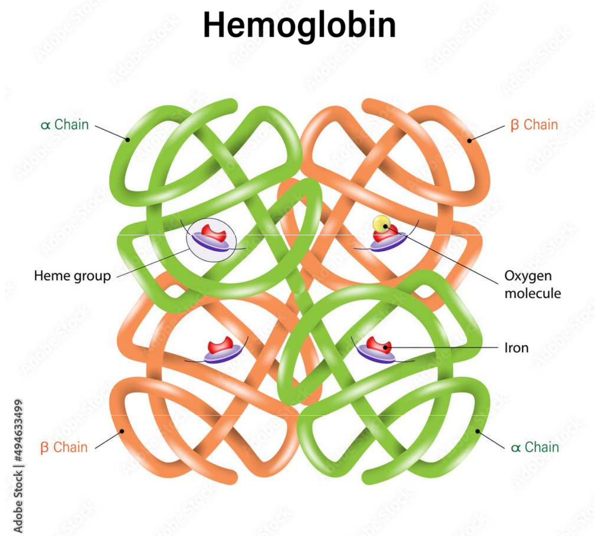


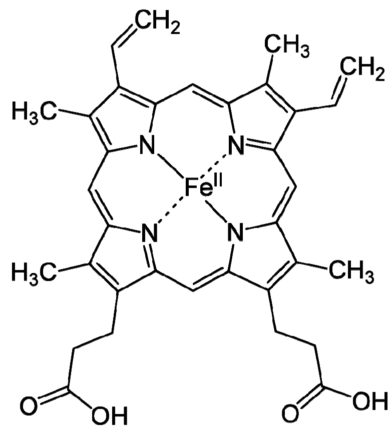
Heme b group

4c) Hemoglobin (Hb)

- Approx. 250 million Hemoglobin molecules per one red blood cell!
- 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 x 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 x 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







Heme b group

Blood KEY POINTS

- Blood and lymph transport materials to and from body tissues
- Blood is about 55% to 60% plasma and 40% to 45% formed elements (white and red blood cells and blood platelets)
- Oxygen travels through the body by binding to hemoglobin in red blood cells
- An increase in blood viscosity results in resistance to flow

KEY POINTS – Cardiovascular system

- The pacemaker of the heart is the SA node; it establishes heart rate and coordinates conduction
- The autonomic nervous system or the endocrine system can alter heart rate and contraction strength
- An ECG records the heart's electrical function and can be used to detect cardiac disorders

Vascular system

- Arteries
- Arterioles
- Capillaries
- Venules
- Veins

Carry blood away from the heart

Carry blood back to the heart

Pulmonary VEINS carry oxygenated blood from the lungs to the heart

Pulmonary ARTERIES carry blood with lower oxygen levels to the lungs

Vascular system

- Arteries
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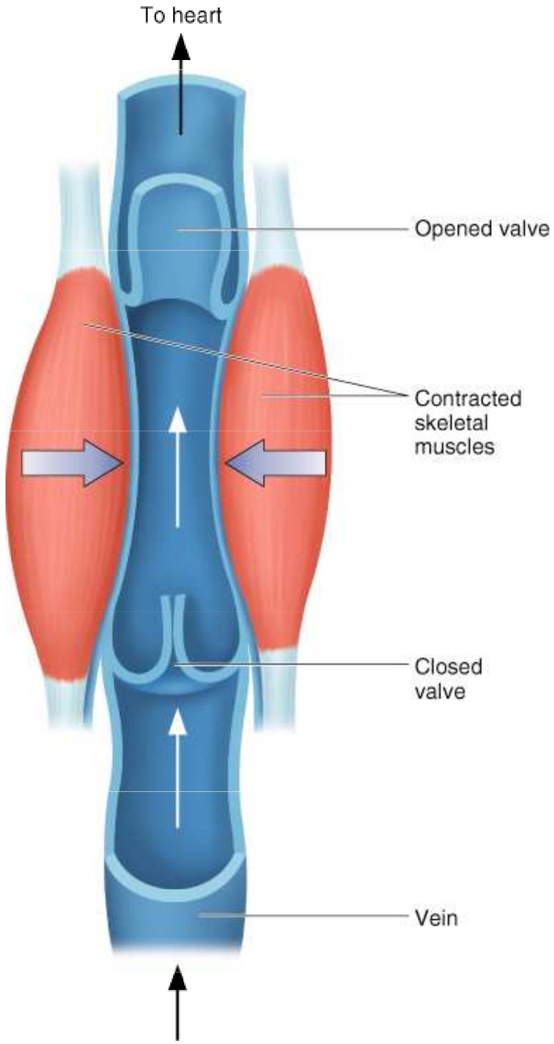
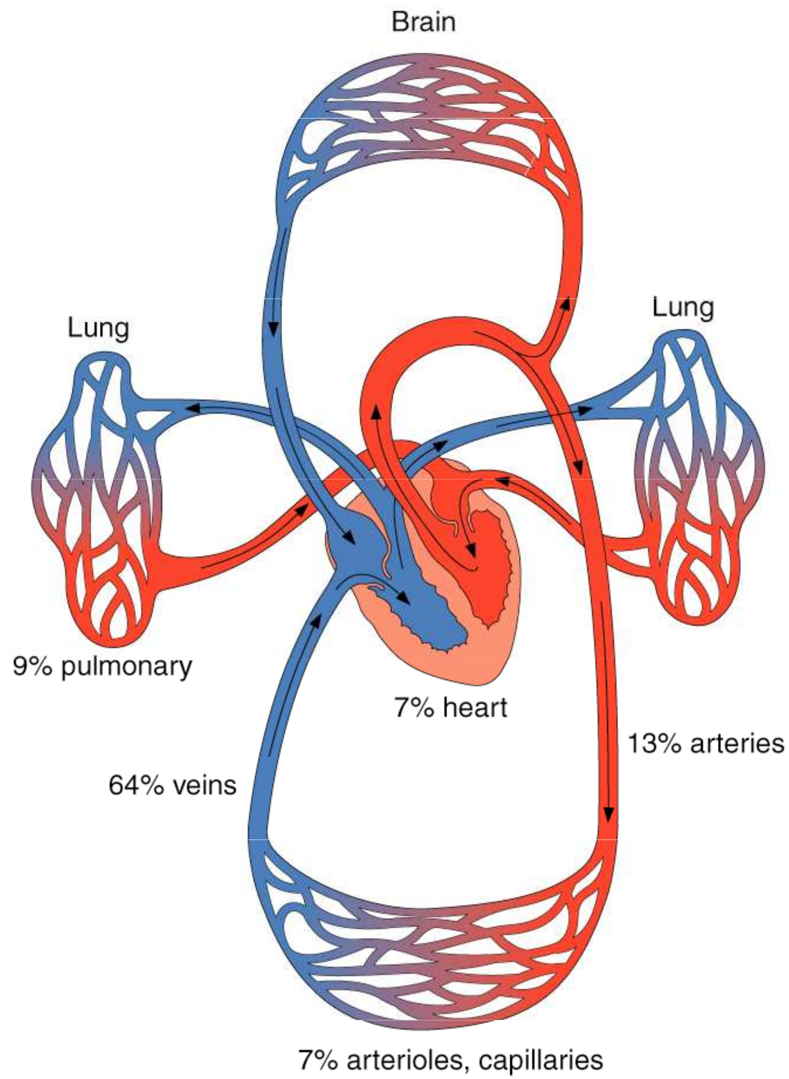


Blood distribution

- Matched to overall metabolic demands
- Autoregulation—arterioles within organs or tissues dilate or constrict in response to the local chemical environment
- Extrinsic neural control—sympathetic nerves within walls of vessels are stimulated causing vessels to constrict
- Determined by the balance between mean arterial pressure and total peripheral resistance



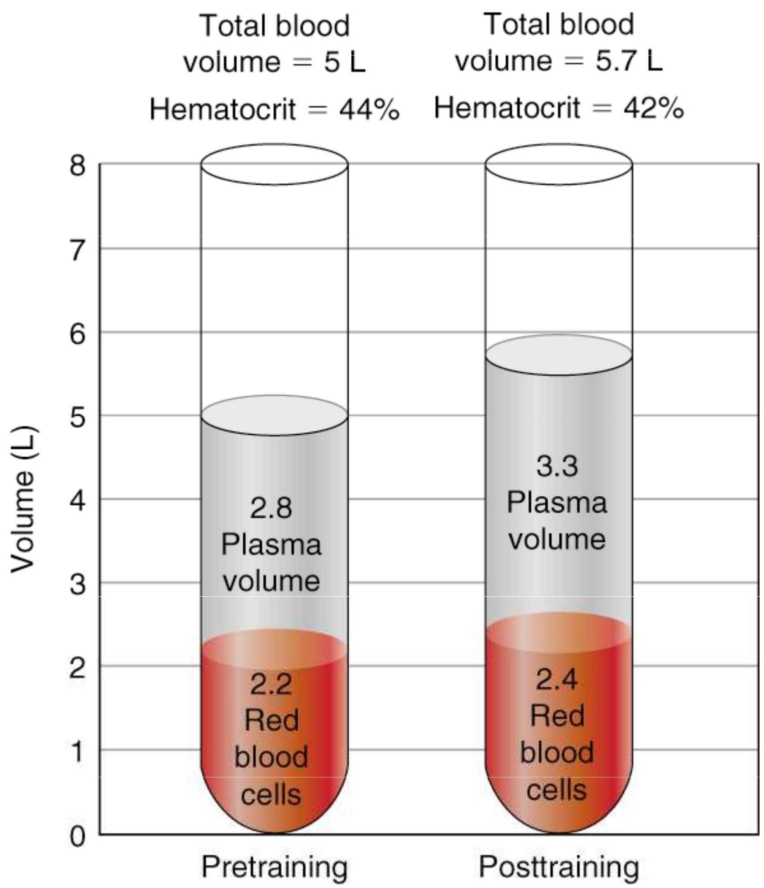
Blood Flow Increases with Training

- **Increased capillarization**
  - of trained muscles (higher capillary-to-fiber ratio)
  - and in the lungs
- **Greater opening** of existing capillaries in trained muscles
- More effective **blood redistribution**—blood goes where it is needed – vasoconstriction and vasodilation
- **Blood volume** increases

Blood Volume and Training

- Endurance training, especially intense training, increases blood volume
- Blood volume increases due primarily to an increase in plasma volume (increases in ADH, aldosterone, and plasma proteins cause more fluid to be retained in the blood)
- Red blood cell volume increases, but increase in plasma volume is higher; thus, hematocrit decreases
- Blood viscosity decreases, thus improving circulation and enhancing oxygen delivery
- Changes in plasma volume are highly correlated with changes in SV and VO_2max

Blood and Plasma Volume and Training



Let's try this:

Name a parameter we talked about and answer the following:

1. Describe chosen parameter in one sentence
2. What is the abbreviation used for this parameter
3. What happens with this parameter with training

Example: Resting heart rate

1. Number of heart beats per minute
2. BPM (beats per minute)
3. It decreases

- Resting heart rate
- Maximal heart rate
- Heart size
- Stroke Volume
- Cardiac output
- Blood flow
- Systolic blood pressure
- Diastolic blood pressure
- Blood volume
- Hematocrit
- Plasma volume

Thank you!