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Introduction to Biophysical Aspects of Human Movement (APA-1161)

Exercise physiology (Cartiopulmonary systems)
November 27, 2012

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TODAY

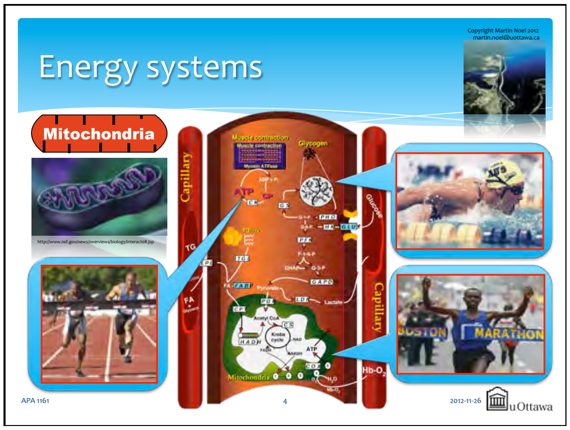
Lesson Plan

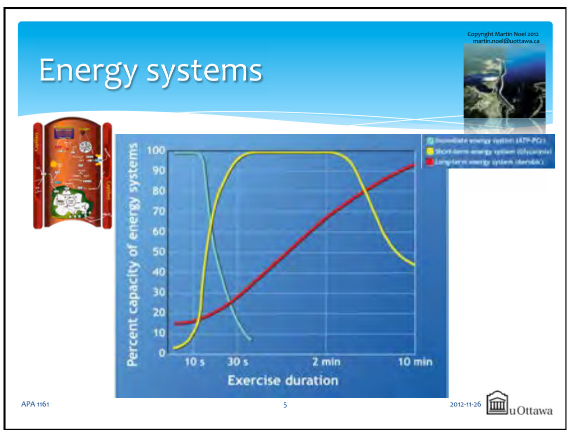
- Overview of O2 uptake
- Pulmonary system
  - Anatomy
  - Volumes
  - Minute ventilation
  - Valsalva
  - Gaz exchange / Hb
  - Ventilation control
- Cardiovascular system
  - Anatomy
  - Blood pressure
  - Blood Flow
  - Heart Rate

Objectives

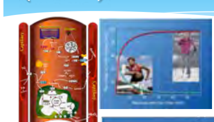
- Understand the basic concepts of pulmonary ventilation
- Identify the adaptive mechanism of ventilation during exercise
- Describe the interaction among cardiac output and heart rate
- Differentiate estimated vs measured heart rate
- Discuss cardiovascular response during exercise

Review from last week





Energy systems
(In brief)

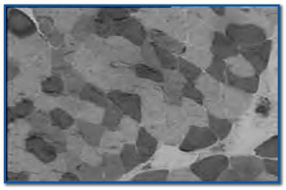


Duration of maximal exercise

	Seconds			Minutes					
	10	30	60	2	4	10	30	60	120
Percentage anaerobic	90	80	70	50	35	15	5	2	1
Percentage aerobic	10	20	30	50	65	85	95	98	99

Muscle fibres
(Biopsie)

- Fibre types
  - I, IIA, IIB



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Muscle fibres
(Biopsie)

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	Type I fibers (red)	Type II a fibers (red)	Type II b fibers (white)
Contraction time	Slow	Moderately Fast	Very fast
Size of motor neuron	Small	Medium	Very large
Resistance to fatigue	High	Fairly high	Low
Activity Used for	Aerobic	Long-term anaerobic	Short-term anaerobic
Maximum duration of use	Hours	<30 minutes	<1 minute
Power produced	Low	Medium	Very high
Mitochondrial density	Very High	High	Low
Capillary density	High	Intermediate	Low
Oxidative capacity	High	High	Low
Glycolytic capacity	Low	High	High
Major storage fuel	Triglycerides	Creatine phosphate, glycogen	ATP, Creatine phosphate
Note	Consume lactic acid	Produce lactic acid and Creatine phosphate	Consume Creatine phosphate

Muscle contraction

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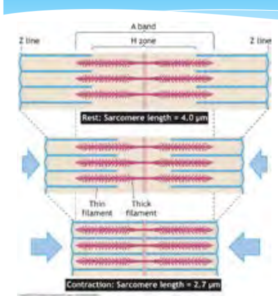

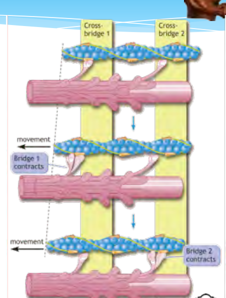

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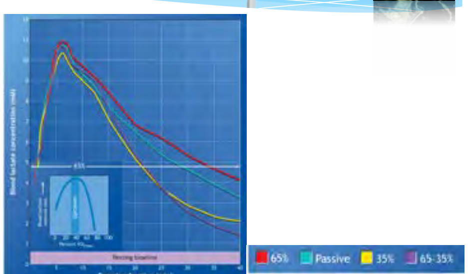
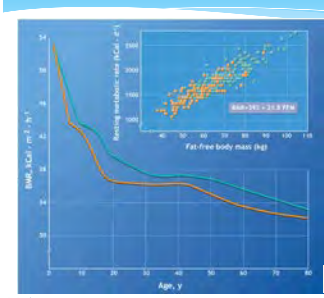
Energy systems
(Recovery)

	Recuparation time			
	Minimum	**Incomplete**	**90-95%**	**Complete**
PCr	2 min			5 min
Glycolisis	5 hrs		18 hrs	72 hrs
Oxidative	30min-1h	2-3 hrs	18 hrs	48 hrs

Energy systems
(Recovery)



Resting energy expenditure



MET
Metabolic equivalent
3.5 $mlO_2 \cdot kg^{-1} \cdot min^{-1}$

TODAY

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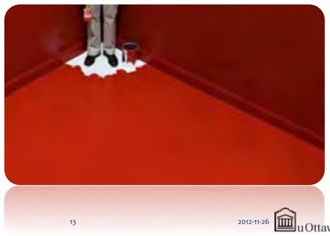
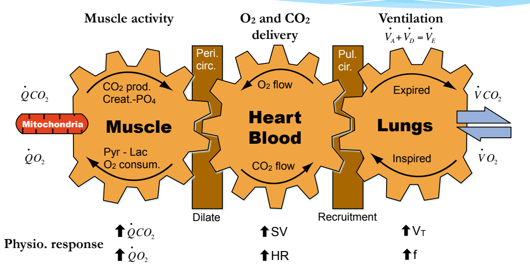
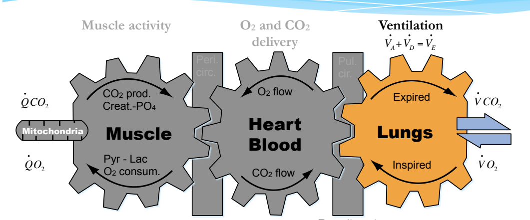


Oxygen uptake



(Adapted from: Wasserman et al. Principles of Exercise Testing and Prescription, Lea & Febiger,1987)

Oxygen uptake



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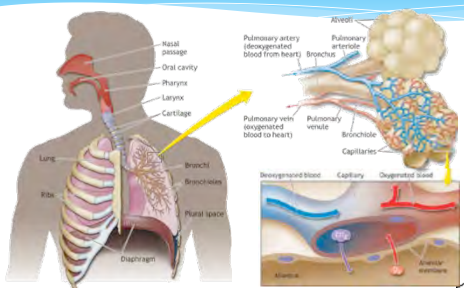
Pulmonary system

- Volumes
- Minute ventilation
- Valsalva
- Gaz exchange / Hb
- Ventilation control

Pulmonary system
(Anatomy and structure)

- **Anatomy of ventilation**
  - Pulmonary ventilation is the process of moving and exchanging ambient air with air in the lungs
  - Air enters the nose and mouth → trachea and adjusts to body temperature, is filtered and humidified → two bronchi → bronchioles → alveoli

Pulmonary system
(Anatomy and structure)



Pulmonary system
(Anatomy and structure)

- **Lungs**
  - Provide the gas exchange surface that separates blood from the surrounding alveolar gaseous environment
  - Oxygen transfers from alveolar air into alveolar capillary blood while the blood's carbon dioxide moves into the alveoli and then into ambient air
  - An average-sized adult's lungs weigh approximately 1 kg, and has a volume of 4-6 L
  - Lung tissue consists of 10% solid tissue and the rest is filled with air and blood

Pulmonary system
(Anatomy and structure)

- **Alveoli**
  - There are more than 600 million alveoli that provide the surface for gas exchange between lung tissue and blood
  - Alveoli receive the largest blood supply of all the organs
  - Capillaries and alveoli lie side by side with the surface as thin as possible to facilitate rapid exchange of gases
  - Each minute at rest, 250 mL of O_2 leaves the alveoli and enters the blood and 200 mL of CO_2 diffuses in the opposite direction

Pulmonary system
(Anatomy and structure)

Where is air almost completely humidified?

a) In the lungs
b) In the trachea
c) In the alveoli
d) In the nose

Pulmonary system
(Anatomy and structure)

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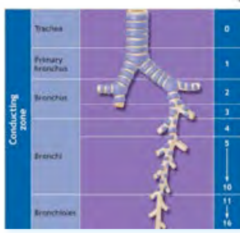
- Ventilatory system:
  - Conducting zones
    - Considered anatomic dead space
  - Functions
    - Air transport, humidification, warming, particle filtration, vocalization, immunoglobulin secretion



Pulmonary system
(Anatomy and structure)

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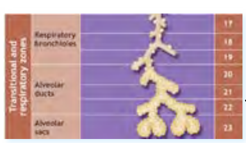
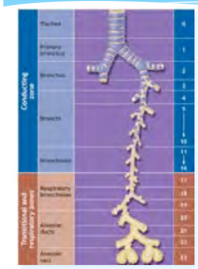
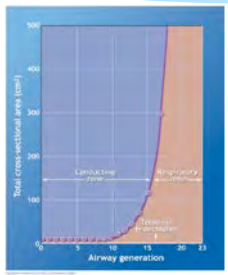
- Ventilatory system:
  - Transitional and respiratory zones
  - Functions
    - Gas exchange, surfactant production, molecule activation and inactivation, blood clotting regulation, and endocrine function



Pulmonary system
(Anatomy and structure)



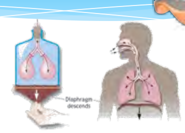


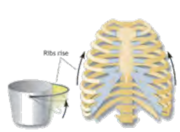
Pulmonary system
(Anatomy and structure)

- Fick`s Law
  - Adolf Eugen Fick, German physiologist
    - Also invented contact lenses
  - Governs the diffusion of gas across a fluid membrane
    - States that a gas diffuses through a sheet of tissue at a rate:
      - Directly proportional to the tissue area, a diffusion constant, and the pressure differential of the gas on each side of the membrane
      - Inversely proportional to tissue thickness
  - The pressure differential between the air in the lungs and the lung–chest wall interface causes the lungs to adhere to the chest wall and follow its every movement

Pulmonary system
(Anatomy and structure)

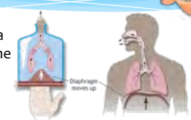
- **Breathing (Inspiration)**
  1. Diaphragm contracts, flattens, and moves downward toward the abdominal cavity
  2. Elongation and enlargement of the chest cavity expands the air in the lungs, causing its intrapulmonic pressure to decrease to slightly below atmospheric pressure
  3. Lungs inflate as the nose and mouth suck air inward
  4. Finishes when thoracic cavity expansion ceases, causing equality between intrapulmonic and ambient atmospheric pressure

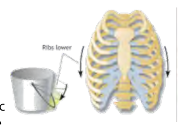




Pulmonary system
(Anatomy and structure)

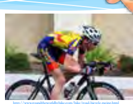
- **Breathing (Expiration)**
  - During rest and light exercise represents a passive process of air movement out of the lungs resulting from:
  - Natural recoil of the stretched lung tissue and relaxation of the inspiratory muscles
  - Phases:
    1. Sternum and ribs drop, diaphragm rises, decreasing chest cavity volume and compressing alveolar gas so air moves from respiratory tract to atmosphere
    2. Ends when the compressive force of expiratory muscles ceases and intrapulmonic pressure decreases to atmospheric pressure



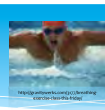


Pulmonary system
(Anatomy and structure)

- Breathing (Inspiration)
  - During exercise
    - the scaleni and external intercostal muscles between the ribs contract, causing the ribs to rotate and lift up and away from the body
    - Inspiratory action increases during exercise when the diaphragm descends, the ribs swing upward, and the sternum thrusts outward
    - Athletes often bend forward from the waist to facilitate breathing following exercise because:
    - Promotes blood flow back to the heart
    - Minimizes antagonistic effects of gravity on the usual upward direction of inspiratory movements



Pulmonary system
(Anatomy and structure)

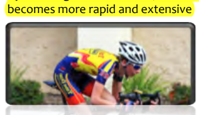


Inspiration during exercise

- During exercise, the scaleni and external intercostal muscles between the ribs contract, causing the ribs to rotate and lift up and away from the body
- Inspiratory action increases during exercise when the diaphragm descends, the ribs swing upward, and the sternum thrusts outward
- Athletes often bend forward from the waist to facilitate breathing following exercise because:
  - Promotes blood flow back to the heart
  - Minimizes antagonistic effects of gravity on the usual upward direction of inspiratory movements

Expiration during exercise

- Internal intercostal and abdominal muscles act powerfully on the ribs and abdominal cavity to reduce thoracic dimensions
- By reducing the dimensions, exhalation becomes more rapid and extensive

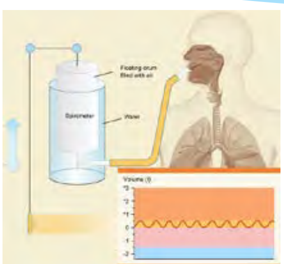


Pulmonary system
(Anatomy and structure)

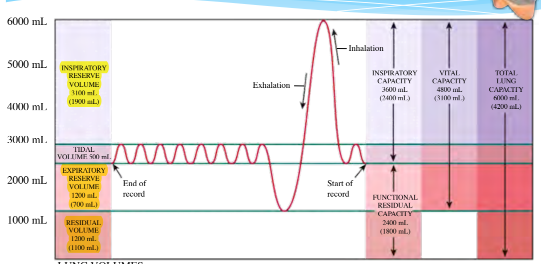
What law governs gas diffusion through the alveolar membrane?

a) Fick's law
b) Kohn's law
c) Law of gas diffusion
d) Newton's third law of motion

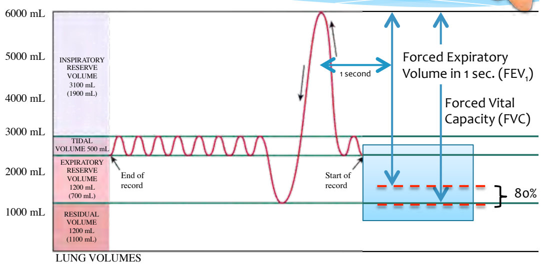
Pulmonary system
(Volumes)



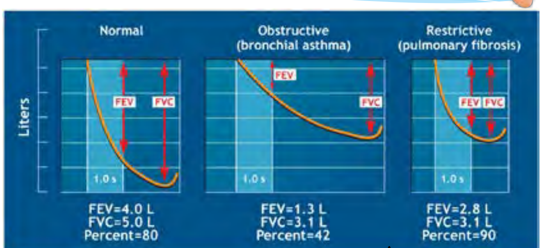
Pulmonary system
(Volumes)



Pulmonary system
(Volumes)



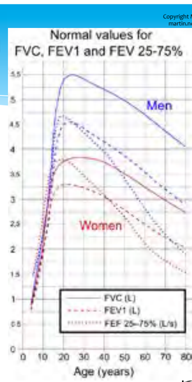
Pulmonary system
(Volumes)



Pulmonary system
(Volumes)

Normal values

Measurements	Values	
	Male	Female
Forced Volume capacity (FVC)	4.8L	3.7L
Tidal volume (Vt)	500ml	390ml
Total lung volume (TLC)	6.0L	4.7L

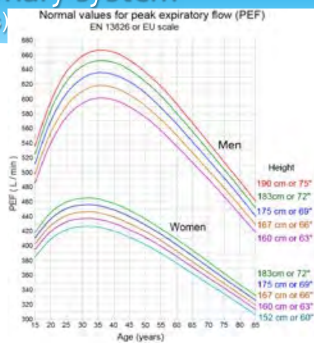


Average values for forced vital capacity (FVC), forced expiratory volume in 1 second (FEV1) and forced expiratory flow 25–75% (FEF25–75%), according to a study in the United States 2007 of 3,600 subjects aged 4–80 years.

Y-axis is expressed in litres for FVC and FEV1, and in litres/second for FEF25–75%

Stanojevic S, Wade A, Stocks J, *et al.* (February 2008). "Reference Ranges for Spirometry Across All Ages: A New Approach". *Am. J. Respir. Crit. Care Med.* **177** (3): 253–60.

Pulmonary system
(Volumes)



Nunn AJ, Gregg I (April 1989). "New regression equations for predicting peak expiratory flow in adults". *BMJ* **298** (6680): 1068–70

Pulmonary system
(Anatomy and structure)

Calculate your predicted residual lung volume

RLV = 0.0275 • AGE + 0.0189 • Ht (cm) – 2.3967

Pulmonary system
(Ventilation)

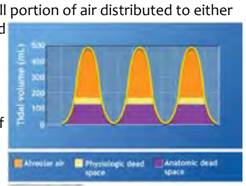
- Minute ventilation
  - The volume of air breathed each minute
  - Averages 6 L
  - Minute ventilation (V_E) = Breathing rate ÷ tidal volume
  - Can be increased by an increase in the rate or depth of breathing, or both
  - Breathing rate can increase to 35-45 bpm during strenuous exercise in healthy young adults and 60-70 bpm in some elite endurance athletes
  - TVs for trained and untrained individuals rarely exceed 60% of vital capacity

Pulmonary system
(Ventilation)

- Maximum voluntary ventilation
  - Evaluates ventilatory capacity with rapid and deep breathing for 15 seconds
    - Extrapolated to the volume if the subject continued for 1 minute
    - ~25% > ventilation in maximal exercise since exercise does not maximally stress how a healthy person breathes
  - Normal values
    - 140 and 180 L · min^{-1} in healthy, college-aged men
    - 80 and 120 L · min^{-1} in healthy, college-aged women
  - Exercise
    - Exercise training of ventilatory muscles improves their strength and endurance, increasing inspiratory muscle function and MVV

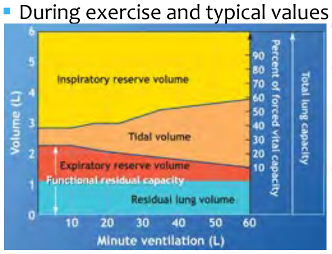
Pulmonary system
(Ventilation)

- Alveolar ventilation
  - Anatomic dead space is the air in each breath that does not enter the alveoli and participate in gaseous exchange with the blood
    - ranges between 150-200 mL
  - Physiological dead space is the small portion of air distributed to either poorly ventilated or poorly perfused
  - About 350 mL of the 500 mL of inspired TV at rest enters into and mixes with existing alveolar air
  - Alveolar ventilation is the portion of inspired air reaching the alveoli and participating in gas



Pulmonary system
(Ventilation)

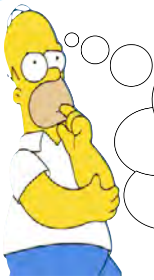
- During exercise and typical values



fyi Typical Values for Pulmonary Ventilation During Rest and Moderate and Intense Exercise

Condition	Breathing Rate (Breaths · min^{-1})	Tidal Volume (L · $Breath^{-1}$)	Plumonary Ventilation (L · min^{-1})
Rest	12	0.5	6
Moderate exercise	30	2.5	75
Intense exercise	50	3.0	150

Pulmonary system
(Anatomy and structure)



Which of the following best describes residual lung volume?

a) The air volume normally in the lungs
b) The air volume remaining in the lungs even after exhaling as deeply as possible
c) The air volume in the lungs after inhaling as deeply as possible
d) The air volume between the lung tissues

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Pulmonary system
(Ventilation)

- War of the gender !
  - Compared to men, women have a reduced lung size and airway diameter, a smaller diffusion surface and static and dynamic lung function measures
    - Leads to expiratory flow limitations, greater respiratory muscle work and use of ventilatory reserve during maximal exercise, particularly in highly trained women

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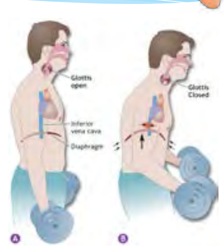
Pulmonary system
(Valsalva maneuver)

- Closing the glottis following a full inspiration while maximally activating the expiratory muscles, creating compressive forces that increase intrathoracic pressure above atmospheric pressure
- Occurs commonly in activities that require a rapid, maximum application of force of short duration



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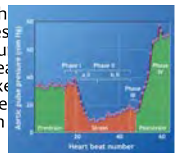
Pulmonary system
(Valsalva maneuver)

- Physiological consequence
  - Performing a prolonged Valsalva maneuver during static, straining-type exercise dramatically reduces venous return and arterial blood pressure
  - This diminishes the brain's blood supply, often producing dizziness or fainting
  - Once the glottis reopens and intrath normalizes, blood flow reestablishes "overshoot" in arterial blood pressu
  - Does not cause relatively large increa pressure during heavy resistance exe exercises greatly increase resistance active muscle with a resulting rise in



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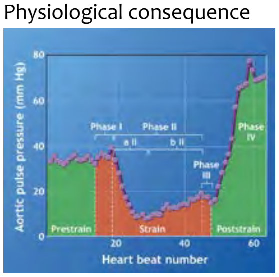
Pulmonary system
(Valsalva maneuver)

- Physiological consequence



Phase 1: Normal breathing

Phase 2: Straining exercise with accompanying Valsalva maneuver

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Pulmonary system
(Anatomy and structure)

Which of the following techniques provides better alveolar ventilation for an athlete during exercise?

a) A faster breathing rate
b) Deeper breathing to increase tidal volume
c) Forced expiration after a normal tidal volume breath
d) Nothing can provide better alveolar ventilation

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Pulmonary system
(Gaz exchange)

- Concentration of ambient air

Partial pressure =

% concentration of specific gaz x Total pressure of gaz mixture

20,93 / 100 x 760 mmHg

0,2093 x 760

159mmHg

TABLE 13.1 • Partial Pressure and Volume of Gases in Dry Ambient Air at Sea Level

Gas	Percentage	Partial Pressure[a] (mm Hg)	Gas Volume ($mL \cdot L^{-1}$)
Oxygen	20.93	159	209.3
Carbon dioxide	0.03	0.2	0.4
Nitrogen	79.04[b]	600	790.3

[a]At 760 mm Hg ambient air pressure.
[b]Includes 0.93% argon and other trace rare gases.

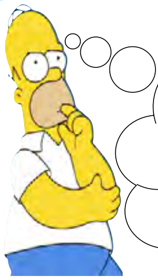
Pulmonary system
(Gaz exchange)

- Definitions
  - PAO2: Partial pressure of oxygen in alveolar chambers
  - PaO2: Partial pressure of oxygen in arterial blood
  - SaO_2%: Percent saturation of arterial blood with oxygen
  - PvO_2: Partial pressure of oxygen in venous blood
  - $PaCO_2$: Partial pressure of carbon dioxide in alveolar chambers
  - $PaCO_2$: Partial pressure of carbon dioxide in arterial blood
  - $PvCO_2$: Partial pressure of carbon dioxide in venous blood

Pulmonary system
(Gaz exchange)

- Definitions
  - SvO_2%: Percent saturation of venous blood with oxygen
  - a-vO_2 diff: Arteriovenous oxygen difference; difference between oxygen carried in arterial blood and carried in venous blood
  - a-$\bar{v}O_2$ diff: Arterial–mixed-venous oxygen difference; difference between oxygen carried in arterial blood and carried in mixed-venous blood
  - $\bar{v}$: mixed-venous blood

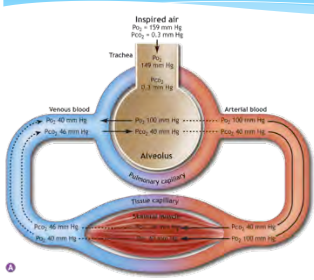
Pulmonary system
(Anatomy and structure)

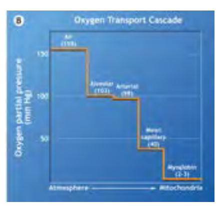


What symbol stands for the partial pressure of oxygen in arterial blood?

a) PAO_2
b) PvO_2
c) PaO_2
d) $SaO_2\%$

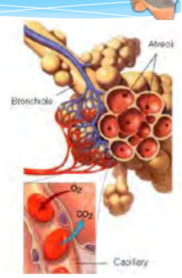
Pulmonary system
(Gaz exchange)





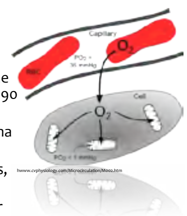
Pulmonary system
(Gaz exchange)

- O_2 travels from a higher to lower pressure as it dissolves and diffuses through the alveolar membranes into the blood
- CO_2 exists under a slightly greater pressure in returning venous blood than in the alveoli, causing net diffusion of CO_2 from the blood into the lungs
- N_2 remains essentially unchanged in alveolar–capillary gas
- Alveolar gas–blood gas equilibrium takes place in ¼ sec



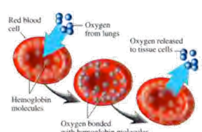
Pulmonary system
(Gaz exchange)

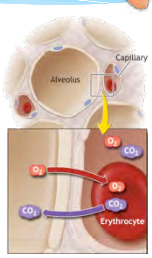
- Gaz transfer in tissues
  - At rest, PO_2 in the fluid outside a muscle cell averages 40 mm Hg and intracellular PCO_2 averages 46 mm Hg
  - In vigorous exercise, PO_2 within muscle tissue falls toward 0 mm Hg, the PCO_2 approaches 90 mm Hg
  - Pressure differences between gases in plasma and tissues establish diffusion gradients
  - O_2 leaves the blood and diffuses toward cells, while CO_2 flows from cells into the blood
  - Blood then passes into the venous circuit for return to the heart and delivery to the lungs



Pulmonary system
(Gaz exchange)

- Transport of O2 in the blood
  - The blood carries oxygen in two ways:
    1. In physical solution dissolved in the fluid portion of blood
    2. In loose combination with hemoglobin, the iron-protein molecule within the red blood cell

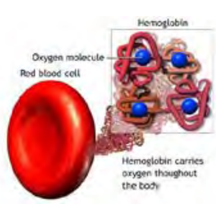




http://gassama.myweb.uga.edu

Pulmonary system
(Gaz exchange)

- Transport of O2 in the blood
  - Hemoglobin
    - Hemoglobin is the iron-containing globular protein pigment
    - Carries 65-70 times more oxygen than normally dissolves in plasma
    - Each of the four iron atoms in the hemoglobin molecule can loosely bind one oxygen molecule: Hb4 + 4 O_2 ⇓◊ Hb4O8
    - The partial pressure of oxygen dissolved in physical solution dictates the oxygenation of hemoglobin to oxyhemoglobin

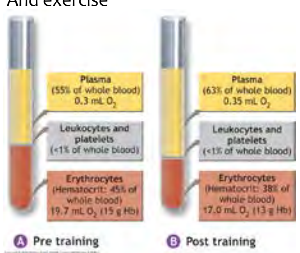


Pulmonary system
(Gaz exchange)

- And exercise
  - Arteriovenous oxygen difference
    - The a-vO2 difference describes the difference between the oxygen content of arterial blood and mixed-venous blood
    - Averages 4-5 mL of O2 per deciliter of blood
    - O2 release from hemoglobin can occur without any increase in local tissue blood flow
    - The amount of O2 released to the muscles increases almost 3 times above that normally supplied at rest
    - An active muscle's uncompromising capacity to use available O2 in its large blood flow supports the position that O2 supply, not muscle O2 use, limits aerobic exercise capacity

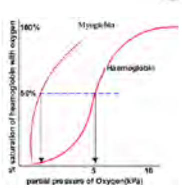
Pulmonary system
(Gaz exchange)

- And exercise



Pulmonary system
(Gaz exchange)

- Myoglobin
  - An iron-containing globular protein in skeletal and cardiac muscle fibers
  - Provides intramuscular oxygen storage
  - Resembles hemoglobin because it also combines reversibly with oxygen but each molecule contains one iron atom while hemoglobin contains four
  - Myoglobin adds additional oxygen to the muscle: $Mb + O_2 \rightleftharpoons MbO_2$
  - Myoglobin facilitates oxygen transfer to the mitochondria when exercise begins and during intense exercise when cellular PO_2 declines rapidly
  - During rest and moderate exercise, myoglobin maintains high oxygen saturation



Pulmonary system
(Anatomy and structure)

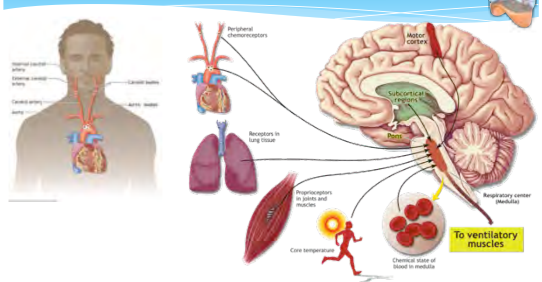
What does the arteriovenous oxygen difference describe?

a) The difference in oxygen content in the blood pre- and post-exercise
b) The difference in oxygen content of arterial blood and mixed-venous blood
c) The range of oxygen content in blood from forced exhale to inhaled deep breath
d) The amount of oxygen attached to hemoglobin immediately preceding a breath

Pulmonary system
(Regulation of pulmonary ventilation)

- Complex mechanisms adjust breathing rate and depth to the body's metabolic needs
- Intricate neural circuits relay information from higher brain centers, lungs, and other sensors throughout the body to coordinate ventilatory control
- The gaseous and chemical states of the blood that bathes the medulla and aortic and carotid artery chemoreceptors also mediate alveolar ventilation
- These control mechanisms maintain relatively constant alveolar gas pressures throughout a broad range of exercise intensities

Pulmonary system
(Regulation of pulmonary ventilation)

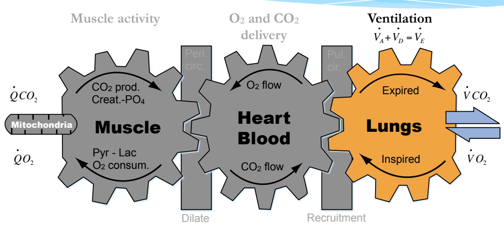


TODAY

Lesson Plan

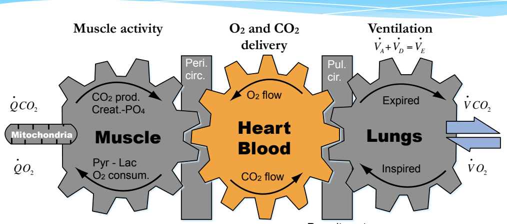
- Overview of O2 uptake
- Pulmonary system
  - Anatomy
  - Volumes
  - Minute ventilation
  - Valsalva
  - Gaz exchange / Hb
  - Ventilation control
- Cardiovascular system
  - Anatomy
  - Blood pressure
  - Blood Flow
  - Heart Rate

Oxygen uptake



(Adapted from: Wasserman et al. Principles of Exercise Testing and Prescription, Lea & Febiger,1987)

Oxygen uptake



(Adapted from: Wasserman et al. Principles of Exercise Testing and Prescription, Lea & Febiger,1987)

TODAY

Lesson Plan

- Overview of O2 uptake
- Pulmonary system
  - Anatomy
  - Volumes
  - Minute ventilation
  - Valsalva
  - Gaz exchange / Hb
  - Ventilation control
- **Cardiovascular system**
  - **Anatomy**
  - **Blood pressure**
  - **Blood Flow**
  - **Heart Rate**

(As far as we know, photo is public domain)

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ACSM certified Exercise Specialist®
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Cardiovascular system

- Anatomy
- Blood pressure
- Blood Flow
- Heart Rate
- Cardiac output

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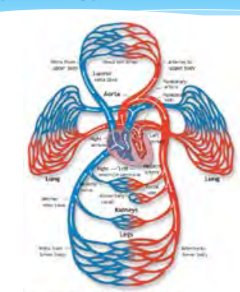
Cardiovascular system
(Anatomy)



Body area	Blood volume mL	Blood volume Percentage
Heart	360	7.2
Lungs		
Arteries	130	2.6
Capillaries	110	2.2
Veins	200	4.0
Systemic		
Aorta, large arteries	300	6.0
Small arteries	400	8.0
Capillaries	300	6.0
Small veins	2300	46.0
Large veins	900	18.0
Total	**5000**	**100.0**

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Cardiovascular system
(Anatomy)

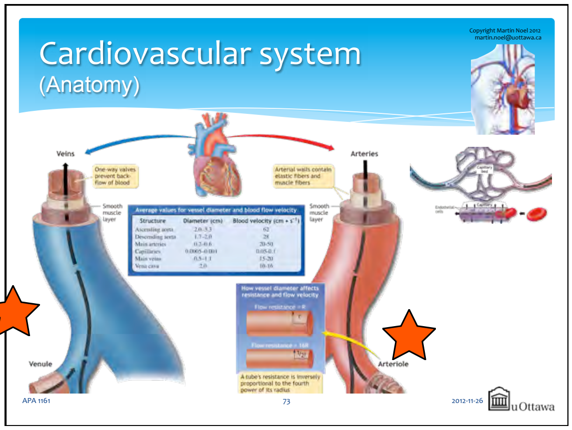
- The Heart
  - Provides the drive for blood flow
  - Four-chambered organ
  - Weighs 11 oz for the average male, 9 oz for the average female
  - Pumps ~70 mL for each beat
  - At rest, ~1900 gals/day or 52 million gals over a 75-year lifetime
  - The heart muscle is called myocardium and its muscle fibers interconnect in latticework fashion to allow the heart to function as a unit

Cardiovascular system
(Anatomy)

Cardiovascular system
(Quiz)

Hollow chambers on the right side of the heart perform which of the following functions?

a) Pump blood throughout the body
b) Pump blood into the lungs
c) Pump blood into the aorta
d) Pump blood into the myocardium


Cardiovascular system
(Anatomy)
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Veins
Arteries
One-way valves prevent back-flow of blood
Arterial walls contain elastic fibers and muscle fibers
Smooth muscle layer
Smooth muscle layer
Average values for vessel diameter and blood flow velocity
Structure | Diameter (cm) | Blood velocity (cm • s⁻¹)
Ascending aorta | 2.0–3.3 | 62
Descending aorta | 1.7–2.0 | 28
Main arteries | 0.2–0.6 | 20–50
Capillaries | 0.0005–0.001 | 0.05–0.1
Main veins | 0.5–1.1 | 15–20
Vena cava | 2.0 | 10–16
How vessel diameter affects resistance and flow velocity
Flow resistance = R
Flow resistance = 16R
A tube's resistance is inversely proportional to the fourth power of its radius
Venule
Arteriole
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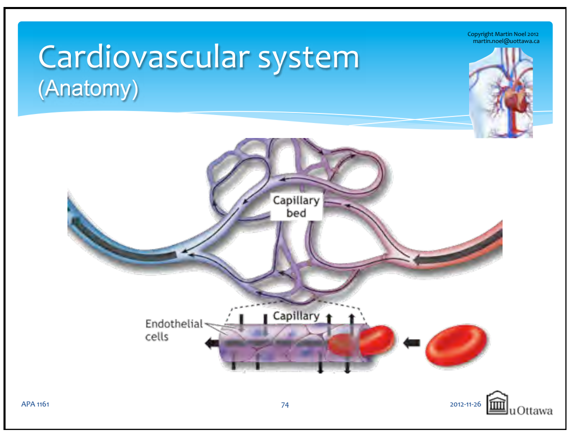
Cardiovascular system
(Anatomy)
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Capillary bed
Capillary
Endothelial cells
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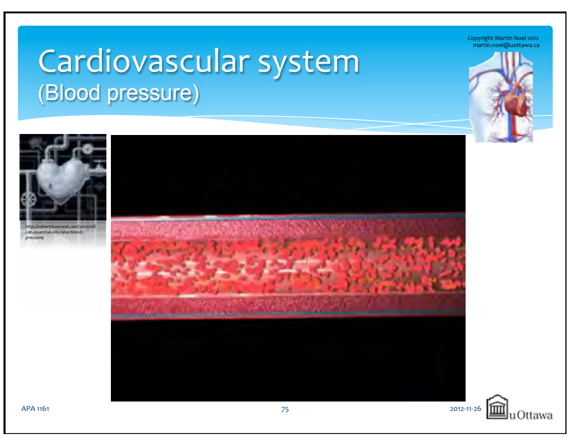
Cardiovascular system
(Blood pressure)
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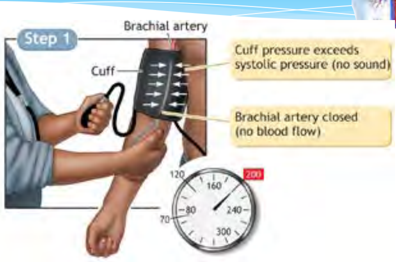
Cardiovascular system
(Blood pressure)

- Peripheral vessels do not permit blood to “run off” into the arterial system as rapidly as it ejects from the heart
- The aorta “stores” a portion of blood, which creates pressure within the entire arterial system
- Arterial blood pressure reflects the combined effects of arterial blood flow per minute and resistance to that flow in the peripheral vasculature
  - Blood pressure = Cardiac output x Total peripheral resistance (TPR)

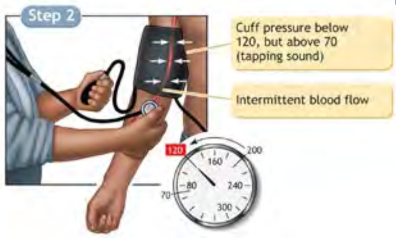
Cardiovascular system
(Blood pressure)

- Blood pressure represents the force exerted by blood against the arterial walls during a cardiac cycle
- Systolic Blood Pressure (SBP): Provides an estimate of the work of the heart and force that blood exerts against the arterial walls during ventricular systole
- Diastolic Blood Pressure (DBP): The relaxation phase of the cardiac cycle
- Indicates peripheral resistance or the ease that blood flows from the arterioles into the capillaries

Cardiovascular system
(Blood pressure)

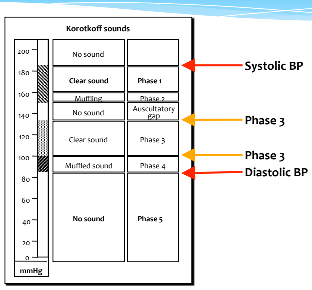


Cardiovascular system
(Blood pressure)

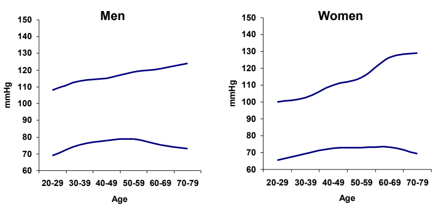


Cardiovascular system
(Blood pressure)

Cardiovascular system
(Blood pressure)

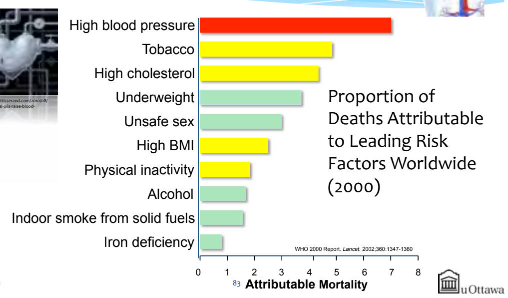


Cardiovascular system
(Blood pressure)



Wilkins et al. *Health Rep* 2010;21:37-46

Cardiovascular system
(Blood pressure)



Proportion of Deaths Attributable to Leading Risk Factors Worldwide (2000)

WHO 2000 Report. *Lancet.* 2002;360:1347-1360

Cardiovascular system
(Blood pressure)

Category	Systolic		Diastolic
Optimal	<120	and / or	<80
Normal	<130	and / or	<85
High-Normal	130-139	and / or	85-89
Grade 1 (mild hypertension)	140-159	and / or	90-99
Grade 2 (moderate hypertension)	160-179	and / or	100-109
Grade 3 (severe hypertension)	≥ 180	and / or	≥ 110
Isolated Systolic Hypertension (ISH)	≥140	and	<90

The category pertains to the highest risk blood pressure
*ISH=Isolated Systolic Hypertension.

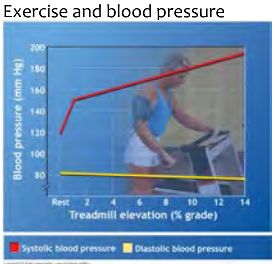
J Hypertens 2007;25:1105-87

Cardiovascular system
(Blood pressure)

- Exercise and blood pressure

Cardiovascular system
(Blood pressure)

- Exercise and blood pressure



Cardiovascular system
(Blood pressure)

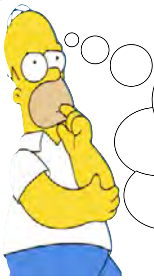
- Exercise and blood pressure

TABLE 15.2 • Comparison of Systolic and Diastolic Blood Pressure During Dynamic Arm and Leg Exercise at Similar Percentages of $\dot{V}O_{2max}$

Percentage of $\dot{V}O_{2max}$	Systolic Pressure (mm Hg)		Diastolic Pressure (mm Hg)	
	Arms	Legs	Arms	Legs
25	150	132	90	70
40	165	138	93	71
50	175	144	96	73
75	205	160	103	75

From Åstrand PO, et al. Intraarterial blood pressure during exercise with different muscle groups. J Appl Physiol 1965;20:253.

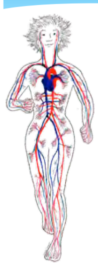
Cardiovascular system (Quiz)



Blood pressure is a product of:

a) Stroke volume and heart rate
b) Heart rate and total peripheral resistance
c) Cardiac output and total peripheral resistance
d) Stroke volume and total peripheral resistance

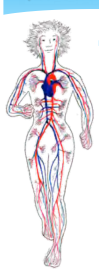
Cardiovascular system (Blood flow)



http://commonsensehealth.com/Health-Conditions/How_to_Improve_Blood_Circulation_Flow.shtml

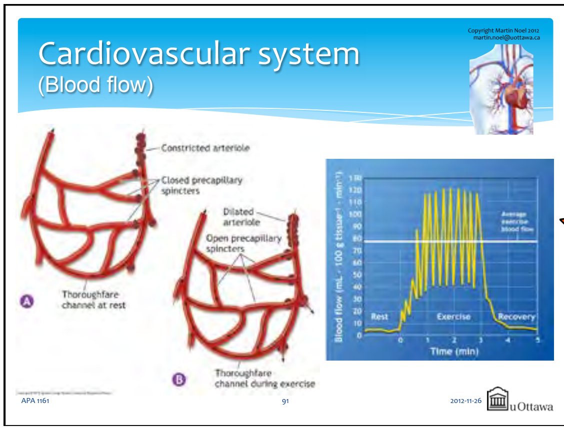
- Equasion:
  - Mean arterial pressure
    - Represents the average force exerted by the blood against the arterial walls during a cardiac cycle
    - Averages 93 mm Hg at rest
    - MAP = DBP + [0.333 (SBP- DBP)]
  - Cardiac output
    - Cardiac output = MAP ÷ Total peripheral resistance
    - MAP and cardiac output estimate the change in total resistance to blood flow in the transition from rest to exercise
  - Total peripheral resistance = MAP ÷ Cardiac output

Cardiovascular system (Blood flow)



http://commonsensehealth.com/Health-Conditions/How_to_Improve_Blood_Circulation_Flow.shtml

- Capilaries
  - The arterioles branch and form smaller and less muscular vessels called metarterioles
  - These vessels end in microscopically small blood vessels called capillaries, which contain 6% of total blood volume
  - The capillary wall usually consists of a single layer of rolled up endothelial cells
  - Some capillaries are so narrow that only one blood cell at a time can squeeze through



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Cardiovascular system
(Blood flow)
Constricted arteriole
Closed precapillary spincters
Dilated arteriole
Open precapillary spincters
Thoroughfare channel at rest
Thoroughfare channel during exercise
Average exercise blood flow
Rest
Exercise
Recovery
Time (min)
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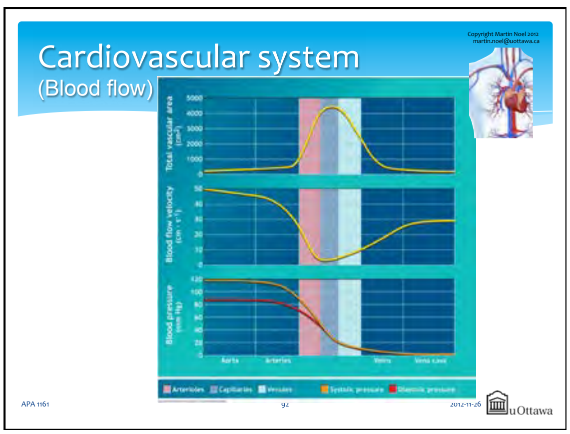

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Cardiovascular system
(Blood flow)
Total vascular area
Blood flow velocity
Blood pressure
Aorta
Arteries
Veins
Vena cava
Arterioles
Capillaries
Venules
Systolic pressure
Diastolic pressure
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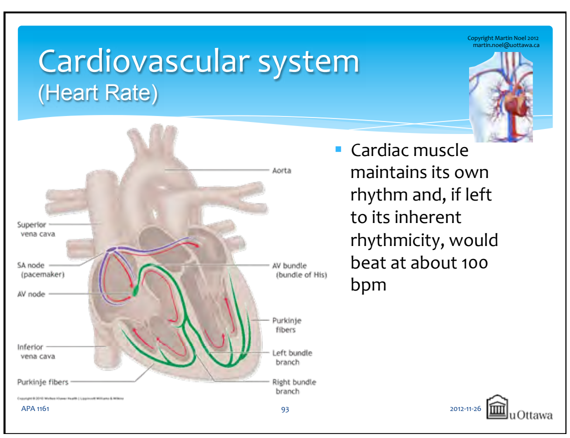

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Cardiovascular system
(Heart Rate)
Aorta
Superior vena cava
SA node (pacemaker)
AV node
AV bundle (bundle of His)
Purkinje fibers
Inferior vena cava
Left bundle branch
Purkinje fibers
Right bundle branch
Cardiac muscle maintains its own rhythm and, if left to its inherent rhythmicity, would beat at about 100 bpm
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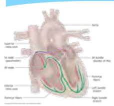
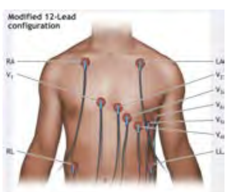
Cardiovascular system
(Heart Rate)

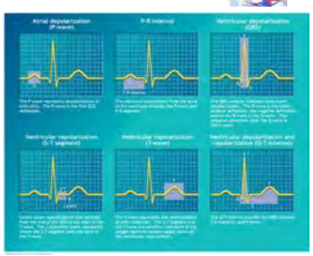


http://videos.howstuffworks.com/science-channel/29732-exploring-time-heart-beat-video.htm

Cardiovascular system
(Heart Rate)

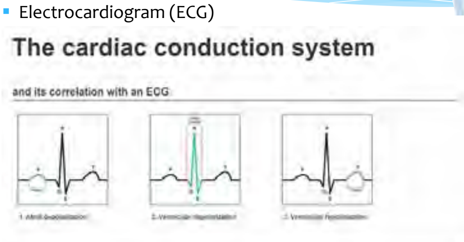
- Electrocardiogram (ECG)





Cardiovascular system
(Heart Rate)

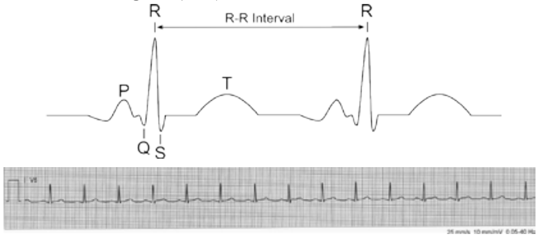
- Electrocardiogram (ECG)



http://www.youtube.com/watch?v=v3b-YhZmQu8

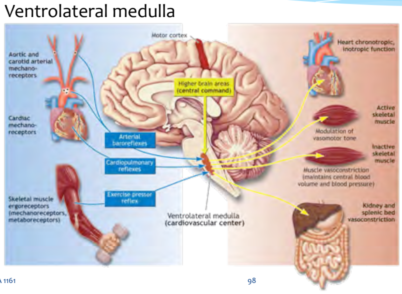
Cardiovascular system
(Heart Rate)

- Electrocardiogram (ECG) and R-R interval



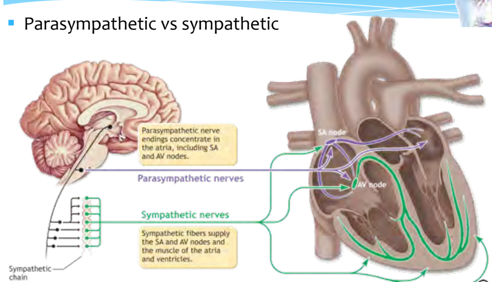
Cardiovascular system
(Heart Rate)

- Ventrolateral medulla



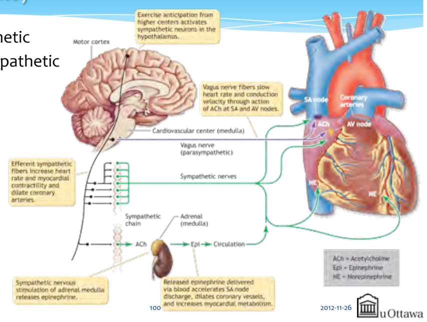
Cardiovascular system
(Heart Rate)

- Parasympathetic vs sympathetic



Cardiovascular system
(Heart Rate)

- Parasympathetic
  vs sympathetic



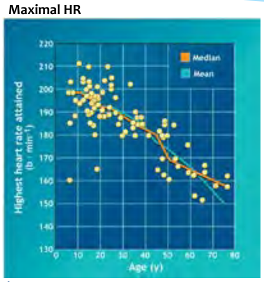
Cardiovascular system
(Quiz)

The inherent rhythmicity or beating of the heart is approximately how many beats per minute?

a) 65 beats
b) 100 beats
c) 75 beats
d) 50 beats

Cardiovascular system
(Heart Rate)

Maximal HR



Resting HR
± 70 bpm

Cardiovascular system
(Heart Rate)

- Resting Heart Rate

WOMEN's RESTING HEART RATE CHART

AGE	18 -25	26 -35	36 -45	46 - 55	56 -65	65+
ATHLETE	54-60	54-59	54-59	54-60	54-59	54-59
EXCELLENT	61-65	60-64	60-64	61-65	60-64	60-64
GOOD	66-69	65-68	65-69	66-69	65-68	65-68
ABOVE AVERAGE	70-73	69-72	70-73	70-73	69-73	69-72
AVERAGE	74-78	73-76	74-78	74-77	74-77	73-76
BELOW AVERAGE	79-84	77-82	79-84	78-83	78-83	77-84
POOR	85+	83+	85+	84+	84+	84+

Cardiovascular system
(Heart Rate)

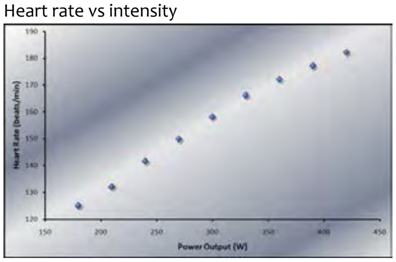
- Resting Heart Rate

MEN's RESTING HEART RATE CHART

AGE	18 -25	26 -35	36 -45	46 - 55	56 -65	65+
ATHLETE	49-55	49-54	50-56	50-57	51-56	50-55
EXCELLENT	56-61	55-61	57-62	58-63	57-61	56-61
GOOD	62-65	62-65	63-66	64-67	62-67	62-65
ABOVE AVERAGE	66-69	66-70	67-70	68-71	68-71	66-69
AVERAGE	70-73	71-74	71-75	72-76	72-75	70-73
BELOW AVERAGE	74-81	75-81	76-82	77-83	76-81	74-79
POOR	82+	82+	83+	84+	82+	80+

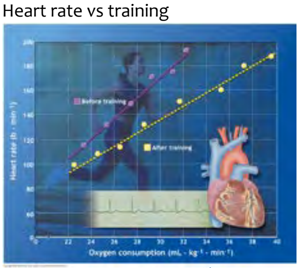
Cardiovascular system
(Heart Rate)

- Heart rate vs intensity



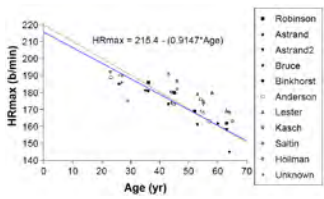
Cardiovascular system
(Heart Rate)

- Heart rate vs training



Cardiovascular system
(Heart Rate)

- Predicted heart rate
  - Sid Robinson (1938)
  - 220-age
    - Astrand and Karvenon – not max. HR
    - Raw mean data compiled in 1971
      - Fox et al. Ann Clin Res 1971;3:404-432



A reproduced figure from the data of Fox et al. which was used to derive the original HRmax=220-age formula. Blue line represents line of best fit. Red line represents 220-age.

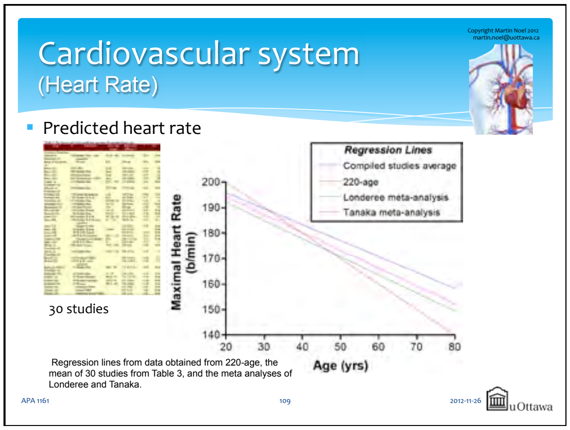
Cardiovascular system
(Heart Rate)

- Predicted heart rate

30 studies

Table 3. The known univariate prediction equations for maximal heart rate.

Study	N	Population	Mean Age (range)	Regression (HRmax=)	r	Sxy
Univariate Equations						
Astrand, in Froelicher (2)	100	Healthy Men – cycle ergometer	50 (20 - 69)	211-0.922a	N/A	N/A
Brick, in Froelicher (2)	7	Women	N/A	226-age	N/A	N/A
Bruce (12)	1295	CHD	52±8	204-1.07a	0.13	22
Bruce (12)	2091	Healthy Men	44±8	210-0.662a	0.19	10
Bruce (12)	1295	Hypertension	52±8	204-1.07a	0.24	16
Bruce (12)	2091	Hypertension + CHD	44±8	210-0.662a	0.10	21
Cooper in Froelicher (2)	2535	Healthy Men	43(11 - 79)	217-0.845a	N/A	N/A
Ellestad in Froelicher (2)	2583	Healthy Men	42(10-60)	197-0.556a	N/A	N/A
Fernhall (13)	276	Mental Retardation	9-46	189-0.56a	0.09	13.8
Fernhall (13)	296	Healthy W & M	N/A	205-0.64a	0.27	9.9
Froelicher (2)	1317	Healthy Men	38.8(28-54)	207-0.64a	0.18	10
Graettinger (14)	114	Healthy Men	(19-73)	199-0.63a	0.22	N/A
Hammond (15)	156	Heart Disease	53.9	209-age	0.09	19
Hossack (16)	104	Healthy Women	(20-70)	206-0.597a	0.21	N/A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Cardiovascular system
(Heart Rate)
Predicted heart rate
30 studies
Regression Lines
Compiled studies average
220-age
Londeree meta-analysis
Tanaka meta-analysis
Maximal Heart Rate (b/min)
200
190
180
170
160
150
140
20 30 40 50 60 70 80
Age (yrs)
Regression lines from data obtained from 220-age, the mean of 30 studies from Table 3, and the meta analyses of Londeree and Tanaka.
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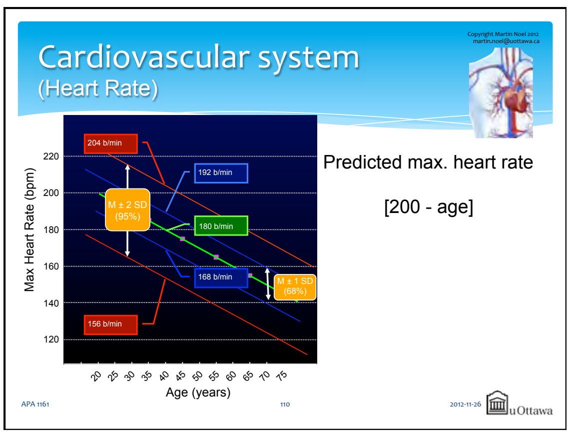
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Cardiovascular system
(Heart Rate)
Max Heart Rate (bpm)
220
200
180
160
140
120
204 b/min
192 b/min
M ± 2 SD (95%)
180 b/min
168 b/min
M ± 1 SD (68%)
156 b/min
20 25 30 35 40 45 50 55 60 65 70 75
Age (years)
Predicted max. heart rate
[200 - age]
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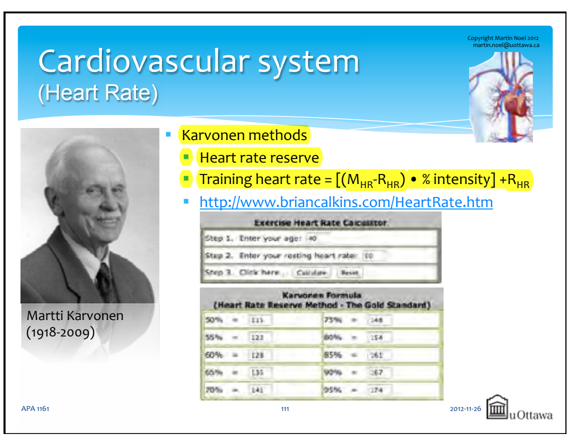
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Cardiovascular system
(Heart Rate)
Martti Karvonen (1918-2009)
Karvonen methods
Heart rate reserve
Training heart rate = [(MHR-RHR) • % intensity] +RHR
http://www.briancalkins.com/HeartRate.htm
Exercise Heart Rate Calculator
Step 1. Enter your age: 40
Step 2. Enter your resting heart rate: 60
Step 3. Click here Calculate Reset
Karvonen Formula
(Heart Rate Reserve Method - The Gold Standard)
50% = 111
55% = 122
60% = 128
65% = 135
70% = 141
75% = 148
80% = 154
85% = 161
90% = 167
95% = 174
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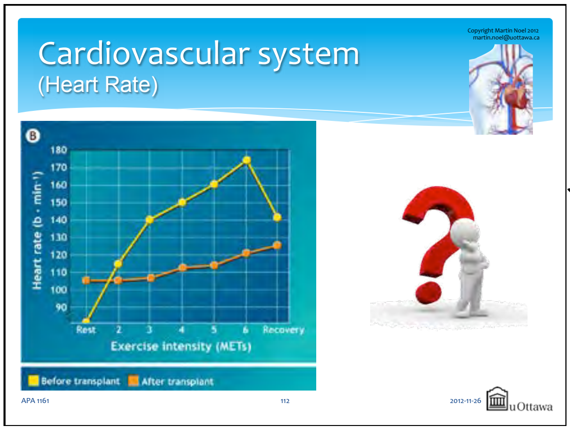
Cardiovascular system
(Heart Rate)
Heart rate (b · min⁻¹)
180
170
160
150
140
130
120
110
100
90
Rest 2 3 4 5 6 Recovery
Exercise intensity (METs)
Before transplant
After transplant
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