Circulation/Transport
General

two major transport systems in body:

A. The Circulatory System
B. The Lymphatic System

circulatory system works in conjunction with lymphatic system
→ they are directly connected to each other

A. Circulatory (cardiovascular) System

circulatory system consists of “plumbing” and “pumps” & circulating fluid
pump = the heart
fluid = blood

blood flows in closed system of vessels over 60,000 miles of vessels (mainly capillaries)

→ arteries → capillaries → veins ← heart

arteries & arterioles
→ take blood away from heart to capillaries

B. Lymphatic System

an open system that returns excess materials in the tissue spaces back to the blood
fluid = lymph
no dedicated pump; muscle contractions move lymph along
lymphatic vessels move lymph in one direction; lymph does not circulate

The Circulatory System
(Cardiovascular System)
major connection between external and internal environment:

everything going in or out of body must go through the circulatory system to get to where it's going

more than 60,000 miles of blood vessels with a pump that beats 100,000 times each day

General Functions of Circulatory System:

A. Transport
B. Homeostasis
C. Protection

A. Transport functions:
1. Pick up food and oxygen from digestive and respiratory systems and deliver them to cells
2. pick up wastes and carbon dioxide from cells and deliver to kidneys and lungs
3. Transport hormones & other chemicals, enzymes etc throughout the body

B. Homeostasis functions:
4. maintain fluid and electrolyte balances in tissues and cells
5. maintain acid/base balances in tissues and cells
6. help regulate temperature homeostasis transfers excess heat from core to skin for removal

C. Protective Functions:
7. Clotting and Inflammation prevent excessive fluid loss and limit the spread of infection
8. Circulating cells and chemicals actively seek out and remove pathogens from the body = "immune system"
The Heart – Anatomy

we are more aware of our heart than most other internal organs

Some ancient Chinese, Egyptian, Greek and Roman scholars correctly surmised that the heart is a pump for filling vessels with blood

Aristotle however thought the heart was the seat of emotion and a source of heat to aid digestion:

- excited → heart beats faster
- “heartache” of grief

his thoughts predominated for over 2000 years before its true nature reemerged

the heart is one of first organ systems to appear in developing embryo

→ heart is beating by 4th week

study of heart = cardiology

no machine works as long or as hard as your heart

beats:
- >100,000 x’s/day
- > 30 Million times each year
- > 3 Billion times in a lifetime to pump > 1 Million barrels of blood

heart is about size and shape of closed fist

heart lies behind sternum in mediastinum,

broad superior border of heart = base

lower border of heart (= apex) lies on diaphragm

heart is enclosed in its own sac, = pericardium (= pericardial sac) (parietal pericardium) composed of tough fibrous outer layer and inner serous membrane

outer surface of heart is also covered with serous membrane (= visceral pericardium) (= epicardium) continuous with the pericardium

between the 2 membranes is pericardial fluid

→ lubrication

pericarditis = inflammation of pericardium, membranes become dry, each heartbeat becomes painful

wall of heart:

epicardium = visceral pericardium thin & transparent serous tissue

myocardium = cardiac muscle cell most of heart branching, interlacing contractile tissue acts as single unit (gap junctions)

endocardium = delicate layer of endothelial cells continuous with inner lining of blood vessels [endocarditis]

Heart Chambers

interior of heart is subdivided into 4 chambers:

- atria = two upper chambers with auricles smaller, thinner, weaker
- ventricles = two lower chambers larger, thicker, stronger left ventricle much larger and thicker than right ventricle left ventricle is at apex of heart

Heart Vessels

There are 4 major vessels attached to heart:

- 2 arteries (take blood away from heart):
  - aorta - from left ventricle
  - pulmonary trunk - from right ventricle
- 2 veins (bring blood back to heart):
  - vena cava (superior & inferior) - to right atrium
  - pulmonary veins (4 in humans) - to left atrium

Heart Valves

There are also 4 one-way valves that direct flow of blood through the heart in one direction:

- 2 Atrioventricular (AV) valves
  - bicuspid (Mitral) valve - separates left atrium and ventricle - consists of two flaps of tissues
  - tricuspid valve - separates right atrium and ventricle - consists of three flaps of tissues

both held in place by chordae tendinae attached to papillary muscles

→ prevent backflow (eversion) keeps valves pointed in direction of flow

- 2 Semilunar valves

  at beginning of arteries leaving the ventricles
  - aortic SL valve at beginning of aorta
  - pulmonary SL valve at beginning of pulmonary trunk
**Blood Vessels**

blood flows in closed system of vessels
over 60,000 miles of vessels (mainly capillaries)

> arteries $\rightarrow$ capillaries $\rightarrow$ veins $\leftarrow$ heart

**arteries & arterioles**
- take blood away from heart to capillaries

**capillaries**
- actual site of exchange

**venules & veins**
- bring blood from capillaries back to heart

**Histology of Vessels**

walls of arteries and veins consist of three layers:

a. **Tunica Externa**

b. **Tunica Media**

c. **Tunica Interna**

a. **Tunica Externa (= T. adventitia)**

- outer loose connective tissue
- anchors the vessel and provides passage for small nerves, lymphatic vessels and smaller blood vessels

b. **Tunica Media**

- middle, made mainly of smooth muscle with some elastic tissue and collagen fibers
- strengthens vessel walls
  - prevent high pressure from rupturing them
- allows vasodilation and vasoconstriction
- usually the thickest layer, especially in arteries

c. **Tunica Interna (= T. Intima)**

- inner endothelium
- exposed to blood
- when damaged or inflamed induce platelets or WBC's to adhere
  - may lead to plaque buildup and atherosclerosis
- aneurysm = a weak point in arterial wall forms
  - Is a bulging sac that may rupture or put pressure on nearby brain tissue, vessels or other passageways.
  - usually due to degeneration of the tunica media, atherosclerosis or hypertension
  - Most common in abdominal aorta, renal arteries and circle of Willis

**Types of Blood Vessels**

1. **Arteries & Arterioles**

- built to withstand the greatest pressure of the system
  - strong resilient walls,
  - thick layers of connective tissues
  - more muscular than veins

- arteries and arterioles typically contain ~25% of all blood in circulation
  - 15% in arteries; 10% in arterioles

- pressure is variable
  - MAP ~ 93 varies from 100 – 40 mmHg

- most organs receive blood from >1 arterial branch
  - provides alternate pathways

2. **Veins & Venules**

- generally have a greater diameter than arteries
- but thinner walls, flaccid
  - more compliant

- three layer are all thinner than in arteries
- tunica adventitia is thickest of three
- but not as elastic as arteries
- little smooth muscle

- ~70% of all blood is in veins & venules
- ~60% in veins, ~10% in venules
- low pressure:
  - 12 – 8 mmHg venules
  - 6 – 1 mmHg veins
  - larger veins near 0

- many of the medium veins, especially in limbs
  - have = 1 way valves

3. **Capillaries:**

- actual site of exchange of materials
  - the rest is just pumps and plumbing

- consist of only a single layer of squamous epithelium = endothelial layer (=tunica intima)

- arranged into capillary beds
  - functional units of circulatory system

- capillaries are extremely abundant in almost every tissue of the body

- most of the 62,000 miles of blood vessels is capillaries

- only 5% of blood at any one time is in capillaries
**Circuits of Bloodflow**

arteries, capillaries and veins are arranged into two circuits:

- **pulmonary**: heart → lungs → heart
  - rt ventricle → pulmonary arteries (trunk) → lungs → pulmonary veins → left atrium

- **systemic**: heart → rest of body → heart
  - left ventricle → aorta → body → vena cava → rt atrium

heart is a double pump

- oxygen deficient blood in pulmonary artery and vena cava → usually blue on models

**Anatomy of Circulatory System**

**Major Arteries and Veins**

**Pulmonary Circuit**
- **Arteries**: pulmonary a.
- **Veins**: pulmonary v.

**Systemic Circuit**
- **Veins**: superior vena cava → coronary v. → brachiophalic v. → jugular v. → subclavian v. → axillary v. → brachial v. → inferior vena cava → hepatic v. → hepatic portal v. → superior mesenteric v. → inferior mesenteric v. → renal v. → gonadal v.

**Special Circulation Patterns**

1. **Coronary Circulation (or Cardiac Circulation)**

   - heart needs an abundant supply of oxygen and nutrients
   - myocardium has its own supply of vessels
   - ~5% of blood goes to heart muscle tissue
   - ~10 x’s its “fair share” based on weight alone
   - any interruption of blood flow can cause necrosis within minutes
     - = **myocardial infarction**
   - R & L Coronary Artery branch from aorta just beyond aortic SL valve
   - blood enters when Left Ventricle relaxes (most vessels receive blood when ventricles contract)
   - most blood returns to heart through veins that drain into coronary sinus
   - which empties into Right Atrium beneath entrance of Inferior Vena Cava

2. **Circle of Willis**

   - 7 separate arteries
branching from the internal carotids and vertebral arteries

arterial anastomosis interconnects them to form a circle of connecting arteries at base of brain

→ more than one route for blood to get to brain

3. Hepatic Portal System

veins from spleen, stomach, pancreas, gall bladder, and intestines

superior and inferior mesenteric merge to form hepatic portal vein

do not take blood directly to vena cava

instead take it to liver for "inspection"

- phagocytic cells remove toxins
- vitamins and minerals are stored

Heart Physiology

for the heart to work properly contraction and relaxation of chambers must be coordinated

Histology of Heart

cardiac muscle fibers

- relatively short, thick branched cells
- striated → myofibrils are highly ordered
- usually 1 nucleus per cell
- rather than tapering cells are bluntly attached to each other by gap junctions = intercalated discs

→ myocardium behaves as single unit

but atrial muscles separated from ventricular muscles by conducting tissue sheath

→ atria contract separately from ventricles

cardiac muscle cells cannot stop contracting to build up glycogen stores for anaerobic metabolism

→ need constant supply of oxygen & nutrients to remain aerobic

→ greater dependence on oxygen than skeletal muscles

have exceptionally large mitochondria

- comprise 25% of cell volume (vs skeletal mm→2%)

cells are more adaptable in nutrient use; can use:

- glucose
- fatty acids (preferred)
- lactic acid

Conducting System

cardiac muscle cells are not individually innervated as are skeletal muscle cells

→ they are self stimulating

the rhythmic beating of the heart is coordinated and maintained by the heart conducting system

conducting system consists of:

SA Node

- intrinsic rhythm
- 70-75 beats/min
- initiates stimulus that causes atria to contract (but not ventricles directly due to separation)

AV Node

- picks up stimulus from SA Node
- if SA Node is not functioning it can act as a pacemaker = ectopic pacemaker (usually slower intrinsic rhythm)

AV Bundle (Bundle of His)

- connected to AV Node
- takes stimulus from AV Node to ventricles

Purkinje Fibers

- takes impulse from AV Bundle out to cardiac muscle fibers of ventricles causing ventricles to contract

the heart conducting system generates a small electrical current that can be picked up by an electrocardiograph

= electrocardiogram (ECG; EKG)

ECG is a record of the electrical activity of the conducting system

body is a good conductor of electricity (lots of salts)

potential changes at body's surface are picked up by 12 leads

[ECG is NOT a record of heart contractions]

P wave = passage of current through atria from SA Node

conduction through atria is very rapid atrial depolarization

QRS wave = passage of current through ventricles from AV Node – AV Bundle – Purkinje Fibers

impulse slows as it passes to ventricles ventricular depolarization
T wave = repolarization of ventricles (atrial repolarization is masked by QRS)

by comparing voltage amplitudes and time intervals
between these waves from several leads can get idea of how rapidly the impulses are being conducted and how the heart is functioning

Abnormalities of ECG’s = arrhythmias

1. bradycardia (<60 bpm)
decrease in body temperature
some drugs (eg digitalis)
overactive parasympathetic system
endurance athletes

2. tachycardia (>100 bpm)
increased body temperature → fever
emergencies, stress → activation of sympathetic NS
some drugs may promote fibrillation

3. flutter
short bursts of 200-300 bpm
but coordinated

4. fibrillation
rapid, uncoordinated contractions of individual muscle cells
atrial fibrillation is OK (since it only contributes 20% of blood to heart beat)
ventricular fibrillation is lethal
electrical shock used to defibrillate and recoordinate contractions

→ defective valves
congenital
rheumatic (strep antibodies)
septal defects

Carotid Output
=The amount of blood that the heart pumps/min

\[
\text{CO} = \text{Heart Rate} \times \text{Stroke volume} \\
= 75 \text{b/m} \times 70 \text{ml/b} \\
= 5250 \text{ml/min} (=5.25 \text{ l/min} = \sim1 \text{ gallon/min}) \\
= \sim \text{normal blood volume}
\]

in a lifetime the heart will pump \sim53 million gallons (200 Million L) of blood
during strenuous exercise heart may increase output 4 or 5 times this amount

A. Heart Rate:
innervated by autonomic branches to SA and AV nodes (antagonistic controls)
cardiac control center in medulla (cardiac center)
receives sensory info from:

Baroreceptors (stretch)
in aorta and carotid sinus
increased stretch → slower

5. AV Node Block
normal P - Q interval = 0.12 – 0.20 seconds
changes indicate damage to AV Node
difficulty in signal getting past AV Node

Cardiac Cycle
1 complete heartbeat (takes \sim 0.8 seconds)
consists of:
systole → contraction of each chamber
diastole → relaxation of each chamber
two atria contract simultaneously
as they relax, ventricles contract
relation of ECG to cardiac cycle
contraction and relaxation of ventricles produces characteristic heart sounds: lub-dub

lub = systolic sound
contraction of ventricles and closing of AV valves
dub = diastolic sound
shorter, sharper sound
ventricles relax and SL valves close
abnormal sounds: “murmurs”

B. Stroke Volume:

→normal SV = \sim70 ml
(healthy heart pumps \sim60% of blood in it)
also each side of heart must pump exactly the same amount of blood with each beat

→ otherwise excess blood would accumulate in lungs or in systemic vessels
eg. if Rt heart pumped 1 ml more per beat
within 90 minutes the entire blood volume would accumulate in the lungs
most affected by:
mean arteriole pressure
systemic blood pressure = back pressure
condition of heart tissue
eg. heart contractility, fibrosis indicates amt of damage

Chemoreceptors
monitor carbon dioxide and pH
more CO₂ or lower pH → faster
Physiology of Blood Vessels

Blood circulates in arteries and capillaries by going down a **pressure gradient**

**Blood Pressure**

- the force of the blood flowing through blood vessels
  measured as mmHg [100 mm Hg = 2 psi, tire ~35psi]

depends on diameter of a vessel and its compliance
eg. vasoconstriction raises blood pressure

changes in pressure are the driving force that moves blood through the circulatory system

blood pressure is created by

1. **the force of the heart beat**
   previously discussed
   the heart maintains a high pressure on the arterial end of the circuit

2. **peripheral resistance**
   \[ \text{back pressure, resistance to flow} \]
   mainly depends on diameter of a vessel and its compliance
   eg. vasodilation raises blood pressure

**Measuring Blood Pressure**

use sphygmomanometer

usually measure pressure in the **brachial artery**

procedure:

a. increase pressure above systolic to completely cut off blood flow in artery
b. gradually release pressure until 1st spurt (pulse) passes through cuff
   \[ \text{= systolic pressure} \]
c. continue to release until there is no obstruction of flow sounds disappear
   \[ \text{= diastolic pressure} \]

**normal BP** = 120/80

range: 110-140 / 75-80 [mm Hg]

**top number** = systolic pressure; force of ventricular contraction

**bottom number** = diastolic pressure; resistance of blood flow

may be more important
indicates strain to which vessels are continuously subjected
also reflects condition of peripheral vessels

**Abnormal Blood Pressure**

**Hypotension** = low BP: systolic <100:

usually not a cause for concern

often associated with long healthy life

but. in some may produce dizziness when standing up too quickly (esp in older patients)
may be due to severe bleeding and lead to circulatory shock
may hint at poor nutrition eg. <blood proteins

**Hypertension** = 140/90

if transient is normal: adaptation during fever, exercise, strong emotions
if persistent is a cause for concern

30% of those >50 yrs old suffer from hypertension

usually asymptomatic for first 10-20 yrs = silent killer

prolonged hypertension is a major cause of: heart failure, vascular disease, kidney failure stroke, aneurysms

high blood pressure affected by: heredity, gender (men at slightly higher risk of HBP), age (risk increases after age 35), race (African Americans at higher risk)

**Flow of Blood in Veins**

the blood pressure gradient is the main force that moves blood through arteries, arterioles and capillaries

movement of blood through veins is not pressure driven by the heart

veins have 1-way valves

prevent backflow

most abundant in veins of limbs

quiet standing can cause blood to pool in veins and may cause fainting

**varicose veins:** "incompetent" valves
esp. superficial veins
may be due to: heredity, prolonged standing, obesity, pregnancy

**hemorrhoids:** varicosities of anal veins due to excessive pressure from birthing or bowel movements
venous pumps

muscular pump (=skeletal muscle pump)
during contraction veins running thru muscle are
compressed and force blood in one direction (toward
heart)

respiratory pump
inspiration: increases pressure in abdominopelvic cavity
to push blood into thoracic cavity
expiration: increasing pressure in chest cavity forces
thoracic blood toward heart

veins also act as blood reservoirs
with large lumens and thin walls they are compliant and can
accommodate relatively large volumes of blood.
(60-70% of all blood is in veins at any time)

most organs are drained by >1 vein
→ occlusion of veins rarely blocks blood flow as it does in arteries
→ removal of veins during bypass surgery usually not traumatic

II. Blood Flow & Differential Distribution of Blood

the overall flow of blood to and within a particular
organ or tissue is related to blood pressure and
peripheral resistance

circulation also involves the differential distribution
of blood to various body regions according to
individual needs
→ active body parts receive more blood than inactive parts
→ blood volume must be shifted to parts as they
become more active

deese shifts are regulated by Vasomotor System

blood circulates because of pressure gradients

individual arterioles can increase or decrease their
resistance to blood flow by constricting or
dilating
mediated by autonomic nervous sytem

vasomotor control center in medulla
works in conjunction with cardiac centers

Capillaries & Capillary Beds

capillaries are the actual site of exchange of materials

→ the rest is pumps and plumbing
each capillary <1mm long
thin walled - single cell layer thick
extremely abundant in almost every tissue of body
→ most of 62,000 miles of vessels
usually no cell >0.1 mm away from a capillary
but only contains ~5% of blood in body
variable pressure 35 – 15 mm Hg

blood flows slowest in capillaries
due to greater cross-sectional area of all capillaries combined
→ blood flows 1000x's faster in aorta than in capillaries

provides greatest opportunity for exchange to
occur

Capillary Beds

   capillary beds are the functional units of
   circulatory system
   usually capillaries 10 –100 capillaries are
   organized into each capillary bed

arterioles and venules are joined directly by
metarterioles (thoroughfare channels)
capillaries branch from metarterioles
cuff of smooth muscle surrounds origin of capillary
branches
   = precapillary sphincter

amount of blood entering a bed is regulated by:
→ vasomotor nerve fibers
→ local chemical conditions
**Effects of Aging on CV System**

most noticeable effect of aging on CV system is stiffening of arteries

heart has to work harder to overcome resistance

ventricles enlarge, esp left ventricle
  may get so thick that not enough space to pump blood effectively

valves may thicken and become calcified

impulse conduction along conducting system becomes more difficult
  → increase in arrhythmias or heart block

muscle cells die
  heart becomes weaker
  → lower tolerance to physical activity

Atherosclerosis is main change seen in blood vessels with age

  stiffening of arterial walls with increasing deposits of collagen fibers & declining resilience of elastic fibers

  also decline in responsiveness of baroreceptors so less vasomotor response to changes in blood pressure

results: quick move from lying to standing, blood is drawn away from brain, can cause dizziness or fainting

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**Disorders of the Circulatory System**

**Heart Disease**

can lead to heart attack and ultimately heart failure

leading cause of death in US for both men and women
  → 500,000 deaths/yr 7.2 M/yr worldwide (??)
  → 30% of deaths/yr

most common form is **coronary atherosclerosis**
  often leading to myocardial infarction (heart attack)

**Heart Attack**

heart attack risk is "50% genetic & 50% cheeseburger" begins with the buildup of plaque:

  a. cholesterol in blood infiltrates the arterial wall
  b. immune system dispatches macrophages to consume the cholesterol
  c. macrophages become foam cells full of cholesterol
  d. foam cells accumulate and become a major component of plaque
  e. to keep the arterial wall slick, smooth muscle cells form a cap
  f. foam cells in plaque secrete chemicals that weaken the cap
  g. if the cap cracks, plaque seeps into the blood stream and a clot forms that blocks blood flow

**Abnormal Blood Pressure**

**Hypotension**

low BP → systolic <100
  usually not a cause for concern
  → often associated with long healthy life

but,
  in some may produce dizziness when standing up too quickly (esp in older patients)
  may be due to severe bleeding and lead to circulatory shock
  may hint at poor nutrition
  eg. <blood proteins

**Hypertension**

  if transient is normal: adaptation during fever, exercise, strong emotions

  if persistent is a cause for concern (silent killer)
  30% of those >50 yrs old suffer from hypertension
  usually asymptomatic for first 10-20 yrs = silent killer

high blood pressure affected by:
  gender: men slightly higher risk of HBP
  age: risk increases after age 35
  heredity/race: African Americans at higher risk
  diet: any factors leading to obesity

prolonged hypertension is a major cause of:
  heart failure
  vascular disease
  kidney failure
  stroke
  aneurysms

**Stroke**

sudden death of brain tissue occurring when
cerebral atherosclerosis, thrombosis or hemorrhage of a cerebral aneurysm cuts off blood flow to part of the brain.

effects range from unnoticeable to fatal depending on extent of tissue damage and function of affected tissue

**Varicose Veins**
can occur anywhere on body but most common on legs
veins in legs are largest in body and must counteract gravity to get blood back to the heart
veins become enlarged and valves fail to prevent backflow of blood
often associated with tired, achy, or feeling of heavy limbs
most common in superficial saphenous veins
they are poorly supported by surrounding tissues
many factors contribute to likelihood of varicose veins:
  - **heredity**
    - age esp occur between 18 and 35 yrs, peaks between 50 and 60 yrs
    - gender women are 4 to 1 times more likely to get them
  - pregnancy sometimes form during pregnancy (8-20% chance) then disappear afterwards
  - lifestyle: prolonged sitting or standing daily

**Transposition of the Great Vessels**
the child will develop normally until they begin to walk
the right ventricle will be unable to pump enough blood through systemic circuit