Circulation/Transport
General

two major transport systems in body:

A. The Circulatory System
B. The Lymphatic Sysem

circulatory system works in conjunction with lymphatic system

→ they are directly connected to each other

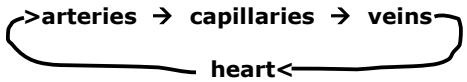
A. Circulatory (cardiovascular) **System**

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 & arterioles
– take blood away from heart to capillaries

capillaries
-actual site of exchange

venules & veins
– bring blood from capillaries back to heart

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 its 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. <u>Transport functions:</u>

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. <u>Homeostasis functions:</u>

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. <u>Protective Functions:</u>

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

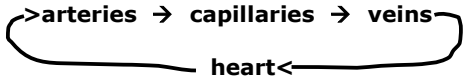
at beginning of arteries leaving the ventricles

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)



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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:
Arteries
aorta
ascending aorta
rt & lft coronary a.
aortic arch
brachiocephalic a.
common carotid a.
internal carotid a.
external carotid a.
subclavian a.
axillary a.
brachial a.
lft common carotid a.
lft subclavian a
descending aorta
celiac trunk
superior mesenteric a.
renal a.
gonadal a.
inferior mesenteric a.
common iliac a.
internal iliac a.
external iliac a.
femoral a.

Veins:
superior vena cava
coronary v.
brachiocephalic 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.

common iliac v.
internal iliac v.
external iliac v.
femoral 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

branchig 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 pacekmaker (usually slower intrinsic rhythm)

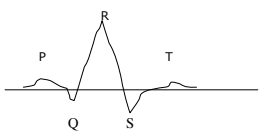
AV Bundle (Bundle of His)
connected to AV Node
takes stimulus from AV Node to ventricles

Purkinje Fibers
takes impulse from AV Bundle out to cardiac mucscle 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

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 ~ 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**"

→ defective valves
congenital
rheumatic (strep antibodies)
septal defects

Cardiac Output

=The amount of blood that the heart pumps/min

CO = Heart Rate X Stroke volume
= 75b/m X 70ml/b
= 5250 ml/min (=**5.25 l/min = ~1 gallon/min**)

= ~ normal blood volume

in a lifetime the heart will pump ~53 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

Chemoreceptors
monitor carbon dioxide and pH
more CO_2 or lower pH → faster

B. Stroke Volume:

→normal SV = ~70 ml

(healthy heart pumps ~60% 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

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]

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**

   → back pressure, resistance to flow

   mainly depends on **diameter** of a vessel and its **compliance**

   eg. **vasoconstriction** raises blood pressure

vasodilation lowers blood pressure

eg. **obesity** leads to many additional vessels that blood must pass through → raises blood pressure

[1lb of fat requires ~7 miles of blood vessels]

eg. any blockage of the normal diameter of a vessel will increase resistance

eg **atherosclerosis** inhibits flow → 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

= systolic pressure

c. continue to release until there is no obstruction of flow
sounds disappear

= 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 failurel stroke, aneuryisms

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

these 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

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 ('07)
→ 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. f the cap cracks, plaque seeps into the blood stream and a clot forms that blocks bloodflow

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Hypotension

low BP → systolic <100
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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
aneuryisms

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 betw 18 and 35 yrs, peaks betw 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 wll be unable to pump enough blood through systemic circuit