INTRODUCTION

System Concept

A. Overall

1. Network of interconnected channels
2. Contains circulating fluid
3. Propelled by muscular pump

B. Organs & Components

1. Blood vessels
    a. Arteries - *[types later]*
    b. Arterioles
    c. Capillaries - *[types later]*
    d. Venules
    e. Veins - *[types later]*
2. Blood - with lymphatic organs & marrow
3. Heart

C. Unique Tissues

1. Cardiac muscle
2. Reticular – in immune organs
3. Blood

Functions

A. [Same as those previously covered under blood]

B. Regulation of other systems

1. Recall this relationship with nervous & endocrine
2. Physical integrator only, though

LYMPHATIC SYSTEM

Relation to Cardiovascular

A. Organs & Components

1. Vessels
   a. No arterial or arteriolar equivalent
   b. Lymphatics
      - Similar to Venules & veins
      - Closely spaced valves - about 2mm apart
   c. Lacteals - similar to capillaries
2. Lymph
   a. Circulating fluid
   b. Comparisons with blood
      - Similar to plasma - higher protein amount
      - Lymphocytes
      - Some granular leukocytes

- No erythrocytes or platelets
- More viscous

3. No heart equivalent

4. Shared structures
    a. Lymph nodes
    b. Spleen
    c. Liver
    d. Tonsils
    e. Red bone marrow

B. Interconnections

1. Thoracic (left lymphatic) duct
    a. Largest lymphatic vessel
    b. Drains most of the body
    c. Empties into left brachiocephalic vein
2. Right lymphatic duct
    1. Drains only upper right side of body
    2. Empties into right subclavian vein

Functions

A. Protein Balance

1. Larger proteins
2. Removed from ECF
3. Introduced into blood circulation

B. Nutrient Absorption

1. Fatty acids, glycerol & cholesterol
2. From intestines

C. Immunity *[previously covered]*

HEART

General Features

A. Concept

1. Highly specialized blood vessel
   a. Theoretical consideration
   b. Equivalent tunics
2. Fibro-muscular pump
   a. Two-sided
      - Right - pulmonary (lungs only)
      - Left - systemic (rest of body)
   b. Right and left work together – parallel
   c. Work in series – regarding the blood

B. Significance

1. Overall importance
   a. One of the more vital organs
   b. Keeps blood moving in vessels

2. Statistics

    a. Beats 100,000 times / 24 hours

    b. Moves 7,200 L blood / 24 hours

Chambers

A. General

1. Hollow spaces within heart

2. Blood moves through in sequence

B. Receiving

1. Right atrium

2. Left atrium

C. Dispensing

1. Right ventricle

2. Left ventricle

Size, Dimensions & Topography

A. General

1. Weight - 250-350 g (female-male)

2. Location - mediastinum of thoracic cavity

3. Orientation

    a. Obliquely positioned

    b. 2/3 to left of midline

B. Aspects

1. General shape - pyramidal or conical
2. Base
    a. Directed superior, posterior & to the right
    b. Opposite vertebrae T5 - T8
    c. 8.75 cm wide
3. Apex
    a. Points inferior, anterior & to the left
    b. 8.75 cm from mid-sternum
    c. In 5th intercostal space (between ribs 5-6)
    d. 5 cm below left nipple

C. Surfaces

1. Sternocostal
    a. Anterior
    b. Mostly right ventricle
2. Diaphragmatic
    a. Inferior
    b. Parts of left & right ventricles
3. Left (pulmonary) - left ventricle
4. Right - mostly right atrium

D. Boundaries *[see handout]*

1. Significance
    a. Precisely positioned

b. Variations indicate abnormality - e.g. enlargement

2. Sequence

a. Superior base

- Third right costal cartilage
- 1.24 cm from sternal center

b. Inferior base - sixth right costal cartilage

c. Apex - fifth left rib interspace *[see above]*

Wall

A. Pericardium

1. Fibrous

a. Not actually part of wall

b. Loose surrounding sac

c. Attached at diaphragm & sternum

d. Relation to major vessels joining heart

- Merges with them
- Continuous with tunica externa

2. Serous

a. Parietal layer

- Outer layer
- Lines fibrous
- Mesothelium

b. Visceral layer - epicardium

- Actual outer heart wall layer

- Continuous with parietal
- Mesothelium & fibro-elastic tissue

3. Pericardial “cavity”

a. Potential space

- Between two serous layers
- Actual space would be pathological

b. Contains serous fluid

- Minute amount
- Lubrication

B. Myocardium

1. General

a. Corresponds to tunica media

b. Most of wall's thickness

c. Two layers

- Superficial - outer, thinner
- Deep - inner, thicker

2. Cardiac muscle

a. Arranged in sheets

- Bundles wind around internal chambers
- Complex spiraling patterns

b. Variable thickness

- Left ventricle - thickest
- Right ventricle - second in thickness
- Left atrium - third in thickness

- Right atrium - thinnest

c. Atrial & ventricular separate

3. Endomysium

a. Connective tissue

b. Surrounds individual muscle cells (fibers)

c. Contains vessels & nerves

4. Trabeculae carneae

a. Thick, irregular bands

b. Ridges

- Project into chambers
- Create rough interior surface

5. Papillary muscles

a. Special trabeculae

b. Elongated conical projections

c. Serve to pull chordae tendineae *[below]*

C. Endocardium

1. General

a. Inner layer - lines chambers

b. Corresponds to tunica interna

2. Structure

a. Endothelium

- Inner portion - in contact with blood
- Simple squamous epithelium

b. Connective - binds endothelium to myocardium

D. Cardiac Skeleton

1. Dense collagenous connective tissue
2. Valve anchorage
3. Myocardial muscle sheet anchorage

Valves & Openings

[Arranged in order of blood flow through the heart]

A. Right atrium

1. Venae cavae
   a. Superior & inferior
   b. Openings into this chamber
2. Tricuspid (right atrioventricular or A-V) valve
   a. Within opening into right ventricle
   b. Surrounded by fibrous ring - cardiac skeleton
   c. Three cusps - flaps or leaflets
   d. Chordae tendineae
      - Dense fibrous bands
      - Attach to free edges of cusps
      - From papillary muscles of ventricle below
3. Valve function *[lab demonstration]*
   a. Controls flow between atrium & ventricle

b. Cause of opening

- Blood falls from atrium into ventricle
- Cusps pushed down into ventricle

c. Cause of closing

- Ventricular contraction
- Blood under pressure from squeezing
- Papillary muscles pull down on chordae
- Cusps pulled hard against blood
- Backflow into atrium prevented

B. Right Ventricle

1. Pulmonary artery - receives blood from this chamber
2. Pulmonary semilunar valve
   a. Three pocket-like flaps
   b. Concave above
   c. Attached to cardiac skeletal ring
3. Valve function *[lab demonstration]*
   a. Cause of opening
      - Blood under pressure from ventricle
      - Flattened upward against artery wall
   b. Cause of closing
      - Blood pulled back when ventricle relaxes
      - Pockets filled with blood
      - Balloon out - meet in middle
      - Opening now blocked

C. Left Atrium

1. Pulmonary veins

a. Two pairs

b. Furnish blood to this chamber

2. Bicuspid (mitral or left atrioventricular or left A-V) valve

a. Only two cusps - mechanically stronger than right

b. Attachment & function same as right A-V

D. Left Ventricle

1. Aorta - receives blood from this chamber

2. Aortic semilunar valve - identical to pulmonary

General Functional Features

A. Myogenicity

1. Heartbeat autonomous

a. Self-stimulating - spontaneous depolarization

b. Can generate own muscle action

2. All cardiac muscle cells have this capability

3. Nervous influences

a. Liberal innervation by autonomic system

b. Can only modify inherent beat

c. Stimulates or inhibits

B. Autorhythmicity

1. Based on myogenicity

2. Frequency of action
    a. Self-stimulation at regular intervals
    b. Produces particular number of beats / min.
3. Restricted to specialized groups of cardiac muscle cells

C. Syncytial Fibers

1. Syncytium = interconnected mass
2. True of cardiac muscle cells (fibers)
3. Intercalated disks
    a. Junctions at ends of adjacent cells
    b. Permit cell-to-cell conduction
    c. Cells stimulate each other
4. Permits sequential contraction throughout heart

D. All-or-none Response

1. Maximum contractile response
    a. Individual muscle cells only
    b. If stimulated to or above threshold amount
    c. Identical to skeletal muscle
2. No response if threshold stimulus not achieved
3. No loss of strength during sequential contraction

E. Long Refractory Period

1. Contraction period = action potential length

2. Unresponsive during contraction
    a. Further stimulation produces no effect
    b. Contrast with skeletal muscle
3. Permits complete squeezing / relaxation rhythm

F. Independent Tone

1. Tone
    a. Pre-contractile tension - muscle stretch
    b. Reflects basic contractile readiness
2. Cardiac independent of nervous system
3. Significance
    a. Measure of general physiological condition
    b. Healthy heart empties blood completely

Conducting System

A. Introduction

1. Concept
    a. Modified cardiac muscle cells
    b. Contractile ability lost
    c. Myogenicity & Autorhythmicity enhanced
2. Importance
    a. Orchestrate contractile cells
    b. Control timing, direction & spread

B. Sinoatrial (S-A) Node

1. Location
    a. Right atrium at superior vena cava junction
    b. Embedded in myocardium

2. Structure
    a. Small mass - 2 mm x 2 cm
    b. Within dense collagenous network
    c. Continuous with surrounding contractile muscle

3. Pacemaker
    a. Autorhythmic - 68 - 72 times / min
    b. More self-excitatory than any other part of heart
    c. Sets pace for heartbeat

4. Impulse spread
    a. Depolarization spreads to surrounding muscle cells
    b. Activated contractile cells pass it on
    c. Sweeping fashion - causes contraction in sequence
    d. Passes through both atria
        - Conduction speed - 0.3 M/sec
        - Time - 0.09 sec spread to farthest point

C. Internodal Pathways

1. Between S-A node & A-V node *[below]*
2. Several interconnections

3. Direct, fast conduction between nodes
    a. Speed - 1 M/sec
    b. Time - 0.03 sec

D. Atrioventricular (A-V) Node

1. Location
    a. Right atrium - near interatrial septum
    b. Embedded just beneath endocardium
2. Structure
    a. Very small - 1 mm x 7.5 mm
    b. Other features similar to S-A node
3. Functions
    a. Strategic delay
        - Junctional fibers receive internodal
        - Speed - 0.01 - 0.02 M/sec
        - Allows time for ventricular filling
    b. One-way conduction - atria to ventricles
    c. Communication between atria & ventricles
        - Joins ventricular conducting system
        - Non-junctional part faster - 0.1 M/sec
        - Time through node - 0.09 sec
    d. Pacemaker
        - Autorhythmic also - 40 - 60/min
        - Normally masked by faster S-A node

E. Ventricular Conducting System

1. General
    a. Purkinje fibers (cells)
    b. Very large & fast - 1.5 - 4 M/sec
2. Bundle of His (A-V bundle)
    a. Joins A-V node
    b. Leads into interventricular septum
    c. Conduction time - 0.04 sec
3. Bundle branches
    a. Right & left forks
    b. Extend down either side septum to apex
4. Other branches
    a. From bundle branches
    b. Smaller - several degrees of branching
    c. Turn back towards base
    d. Conduction time - 0.03 sec to terminals
5. Overall function & significance
    a. Rapid spread _thicker / larger ventricles
    b. Synchronization
        - All parts of ventricles almost simultaneous
        - For effective pumping action
6. Ordinary contractile muscle fibers
    a. Continue depolarization wave
    b. Through thickness of myocardium

c. Speed - 0.3 - 0.5 M/sec

d. Time - 0.03 sec

Cardiac Cycle

A. Concept

1. Actual heartbeat
2. Repeating cycle
   a. Contraction - systole
   b. Relaxation - diastole
3. Sequence
   a. 2 atria contract together
   b. 2 atria relax
   c. 2 ventricles contract together
   d. 2 ventricles relax
4. Mechanical cycle
   a. Different from “electrical” conduction
   b. Caused by conduction rhythm, though
5. Purpose - produces blood pressure

B. Atrial Diastole

1. Relaxation phase
2. Filling with blood - venae cavae & pulmonary veins

C. Atrial Systole

Stimulated to contract by S-A node & spread

D. Ventricular Diastole

1. Overlap
    a. Simultaneous with last half of atrial diastole
    b. Entire heart relaxed
2. Ventricular filling
    a. 30% from atrial systole
    b. 70% from sucking action of ventricular diastole

E. Ventricular Systole

1. Stimulated by ventricular conducting system
2. Relation to atria
    a. Starts at beginning of atrial diastole
    b. Ends well before atria begin systole
3. Sequence
    a. From apex to base
    b. Caused by bundle branch pattern
    c. Produces necessary milking action

Heart Sounds

A. First

1. General
    a. Phonetic - “lubb” - lower pitched

b. Beginning of ventricular systole

c. Lasts 0.14 sec

2. Causes - in descending significance

a. A-V valves close

- Very forceful
- Chordae tend. pull down from contraction
- Ventricular blood attempts to push up
- Mitral closes first in some people

b. Semilunar valves open

- Forcefully flattened against arterial walls
- Pulmonary first in some people

c. Blood rushing - ventricular pressure effects

d. Wall vibrations

- Blood under pressure & contraction forces
- Ventricles, pulmonary trunk & aorta

B. Second

1. General

a. Phonetic - “dupp” - higher pitched

b. Beginning of ventricular diastole

c. Lasts 0.11 sec

2. Causes - in descending significance

a. Semilunar valves close

- Very abruptly

- Blood catches in pockets
- Balloon out - block opening
- Aortic first by a short interval

b. A-V valves open

- Opening snap (o.s.)
- Vacuum in ventricles suck them down
- Elastic recoil from release by chordae tend.
- Blood flowing in from atria

c. Vibrations

- Blood in arteries from valve recoil
- Artery & ventricular walls from vacuum

3. Split

a. Occasionally in 2 parts

b. Significantly earlier closing of aortic valve

C. Third

1. General

a. Very low pitched rumble

b. Very faint - requires electronic detection
c. Middle of ventricular diastole

2. Cause

a. Ventricular filling vibrations

b. From blood bouncing off elastic walls

D. Fourth

1. General

- a. Very low pitched
- b. Very faint - requires electronic detection
- c. During atrial systole

2. Cause

- a. Ventricular filling vibrations - same as third
- b. Later in ventricular diastole than third

E. Abnormal

1. General

- a. Termed murmurs
- b. Pathology
  - Usually from valvular defects
  - May occur when cardiac health good, though

2. Causes

- a. Stenosis
  - Narrowing of valve opening
  - Hissing from pressure change
- b. Regurgitation
  - Leaking valve
  - Gurgling noise
  - Rheumatic fever - scarring of valve

Cardiac Output

A. Concept

1. Measure of heart's efficiency - tone
2. Based on amount of blood pumped out

B. Components

1. Stroke volume (SV)
   a. Amount of blood - in ml
   b. Ejected by ventricle in one beat (systole)
   c. 70 ml normal
   d. 160 ml maximum
   e. Causes of variation
      - Venous return - end-diastolic volume (EDV) – 130ml
      - Systolic force - stretching phenomenon
   f. End-systolic volume (ESV)
      - Amount left in ventricle after systole – ~50ml
      - ∴ SV = EDV – ESV
   g. Ejection fraction -- ~50-65%
2. Heart rate (HR)
   a. Number of beats / min
   b. 68-72 normal
   c. 180 maximum **effective**
      - More is possible
      - CO would decrease – insufficient time for cycling

d. Causes of variation *[details later]*

- Autonomic nervous influence
- Hormonal

C. Expression

1. Equation

$$CO = HR \times SV$$

2. Examples

a. Normal

CO = 70 / min x 70 ml
CO = 4,900 ml (4.9 L) / min

b. During strenuous exercise

CO = 180 / min x 160 ml
CO = 28,800 ml (28.8 L) / min

D. Frank - Starling Law of the Heart

1. Heart empties itself completely with each beat

a. Not all ventricular blood - just new incoming

b. Within normal maximum limits of capability

2. Variability - more blood in will produce more out

3. Significance

a. Adjusts circulating blood volume

b. Variable needs

- Pulmonary gas exchange
- Systemic nutrient & waste exchanges

Regulation & Effects

A. Nervous

1. Central control

a. Brain's medulla oblongata

b. Vasomotor center - autonomic nerve output

c. Hypothalamus - ultimate control

d. Cerebrum - conscious influences

e. Breathing centers

- Medulla & pons
- Coordination with vasomotor
- To control pulmonary blood flow
- *[details later -- respiratory system]*

2. Peripheral nerves - autonomic

a. Parasympathetic division

- Endings at S-A & A-V nodes
- Inhibitory - decreased CO - ESV increased

b. Sympathetic division

- Many more endings - extensive over heart
- Stimulatory - increased CO - ESV decreased

3. Blood vessel effects

a. Control venous return & EDV

b. *[mechanisms later]*

4. Feedback - via baroreceptors
    a. Walls of internal carotid & aorta
    b. Stretch receptors
    c. Monitor blood pressure
    d. Communicate with medulla

B. Hormonal

1. Epinephrine & norepinephrine
    a. Adrenal
    b. Stimulation of HR & SV
    c. Similar sympathetic nerve transmitter - adrenaline
2. T_4 & T_3 - Identical effects to adrenal

C. Ions

1. Calcium
    a. Integral part of normal muscle functioning
        - Different from skeletal muscle
        - Only sodium, influenced inversely by Ca
    b. Hypercalcemia
        - Hypersensitivity & hyperactivity
        - Spastic behavior
    c. Hypocalcemia - depresses
2. Potassium
    a. Integral part of normal muscle functioning
    b. Hyperkalemia - depresses excitability

c. Hypokalemia - no effect

D. Temperature

1. Direct proportion with heart activity

2. Due to basic energy / molecular & ionic activity relation

ELECTROCARDIOGRAPHY

[All Details Given in Lab]

BLOOD VESSELS

Arteries

A. Concept

1. Transport blood away from the heart

2. Carry blood to arterioles

B. Sizes

1. Largest - 25 mm (aorta)

2. Smallest - 100-300 μm (just before arterioles)

C. Structure

[Tunics basically studied in lab -- other features added here]

1. Tunica intima (interna)

2. Tunica media

a. A few to 40-60 layers - each 2.5 μm thick

b. Predominant tissue varies with arterial type

- Smooth muscle & some elastic tissue
- Dense elastic connective & some muscle

3. Tunica adventitia (externa)

a. Dense irregular connective tissue

b. Elastic & collagenous fibers predominate

D. Types

1. General

a. Type categories not absolute

b. Gradual transitions between any 2 adjoining types

2. Elastic (conducting or resistance)

a. Largest arteries

- Aorta
- Major aortic branches
- Pulmonary trunk and major branches

b. Tunica media

- Mostly elastic tissue - distinct circular bands
- Some interspersed smooth muscle layers

c. Function *[details later]*

- Maintain blood pressure
- At correct level for rest of body

3. Muscular (distributing)

a. Medium & small sized arteries

b. Tunica media

- Mostly smooth muscle layers - circular
- Some interspersed elastic connective tissue

c. Function *[details later]*

- Variably control pressure & flow to arterioles
- Via nervous control

Arterioles *[Some consider to be smallest arteries]*

A. Concept

1. Transport blood from smallest arteries to capillaries
2. Exert final pressure & flow control

B. Sizes

1. Largest diameter - 100 μm
2. Smallest diameter - 5 μm

C. Structure

1. Similar to arteries
2. Tunica intima - no difference
3. Tunica media
   a. Primarily muscular
   b. Layers - several to only patchy separate cells
4. Tunica adventitia
   a. Rather delicate connective tissue
   b. Collagenous fibers predominate

D. Types

1. Muscular

a. Largest - 100-50 μm

b. Tunica media - more muscular layers

2. Terminal

a. Medium - 50-20 μm

b. Several levels of branching

3. Metarterioles

a. Smallest - down to 5 μm

b. Open into capillaries

4. Precapillary sphincters

a. Not a vessel type - in wall of end of metarteriole

b. Smooth muscle cell encircling capillary entrance

Capillaries

A. Concept

1. Constitute microcirculation

2. ***Functional units of entire cardiovascular system***

3. Exchanges between blood & tissue fluid

B. Features

1. Size

a. Length - 1 mm

b. Diameter - 4-9 μm

2. Structure

a. Lining endothelium

b. Outer basement membrane

- Gelatinous glycoprotein basal lamina
- Outermost delicate reticular layer

3. Extent

a. Total of about 7 billion

b. Combined length of 60,000 miles

c. Collective inner surface area of 7,000 M^2

d. Any cell less than 100 μm from capillary

C. Arrangement

1. Capillary beds

a. Net-like interconnected groupings

b. Some more direct between arterioles & venules

c. Some more indirect - form most of bed

2. Exceptions to beds

a. Kidney - glomerulus *[details later -- excretion]*

b. Sinusoids *[details below]*

D. Types

1. Continuous

a. Skin, connective tissues, muscle, lung, brain

b. Relatively thick lining squamous cells

c. Junctions between cells

- Tightest in brain - blood-brain barrier
- Looser in other locations

d. Permeable to only water & smaller solutes

2. Fenestrated

a. Kidney, intestines, endocrine glands

b. Relatively thin squamous cells

c. Cells penetrated by pores (fenestrae)

d. Permeable to water & larger solutes (e.g. peptides)

3. Sinusoids

a. Liver, bone marrow, spleen, endocrine glands

b. Irregular shape & diameter - pouch-like

c. Permeability

- Variable - generally like fenestrated
- Some even permeable to proteins

d. Blood flow

- Very slow - permits more interaction
- Primarily in blood processing organs
- Often associated with phagocytic cells

Venules

A. Concept

1. Receive blood from capillaries

2. Transport blood to smallest veins

B. Sizes

1. Largest - 200 μm
2. Smallest - 20 μm

C. Structure

1. Lining endothelium
2. Tunica media
    a. Muscular in largest
    b. Absent in smallest
3. Tunica adventitia
    a. Delicate collagenous connective in largest
    b. Only basement membrane in smallest

D. Types

1. Postcapillaries
    a. Smallest
    b. Permeable
    c. Important site of diapedesis
2. Venules proper

Veins

A. Concept

1. Carry blood from venules
2. Transport blood towards the heart

B. Sizes

1. Generally larger than equivalent arteries

2. Largest - 25 mm (inferior vena cava)

3. Smallest - 200 μm (just after venules)

C. Structure

1. Tunica intima

2. Tunica media

    a. Always much less smooth muscle than arteries

    b. More connective tissue - elastic & collagenous

3. Tunica adventitia

    a. Generally thicker than media

    b. Mostly connective tissue in smaller

    c. Some muscle in larger

    d. Relatively more muscle in largest

D. Types

1. General

    a. Much less distinct than arterial types

    b. One vessel varies in structural details along length

2. Small to medium

    a. Join venules

    b. Smaller branches converge

3. Large

    a. Major branches of venae cavae

    b. Venae cavae

    c. Hepatic portal

Anastomoses

A. Concept

1. Junction of one blood vessel with another
    a. Not same as larger-smaller branch relationship
    b. Vessels of equal size
    c. Between arteries, veins, or artery-vein
2. Bypasses usual artery-arteriole-capillary-venule-vein

B. Significance

1. Provides alternate routes
2. Ensures open channels always present
3. Termed collateral circulation
4. End-arteries - lack anastomoses - blockage more critical

C. Examples

1. Between arteries in joints
    a. Permits flow past temporary blockage
    b. Smaller vessels blocked during movements
2. Brain - extensive
3. Skin - basis for variable heat loss

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Networks (Circulations)

A. Concept

Grouping of vessels for specific purpose

B. Systemic

1. Left heart - atrium & ventricle
2. Aorta & all branches
3. Arterioles from aortic branches
4. Capillaries from arterioles
5. Venules from capillaries - except digestive (& others)
6. Veins from venules - converge to sup. & inf. venae cavae

C. Pulmonary

1. Right heart - atrium & ventricle
2. Pulmonary trunk & all branches
3. Arterioles from pulmonary branches
4. Capillaries of lung alveoli
5. Venules from alveolar capillaries
6. Veins from venules - converge as pulmonary veins

D. Portal (Hepatic Portal)

1. Concept & purpose
    a. Venous drainage from digestive & nearby viscera
    b. To initially send digested nutrients to liver
        - For processing
        - For use
        - For distribution

2. Components

    a. Venules from capillaries - those excepted from systemic network

        - Small intestine
        - Large intestine
        - Stomach
        - Gallbladder
        - Spleen
        - Pancreas

    b. Veins from venules - converge as portal vein

    c. Portal empties into liver

3. Eventual link with systemic network

    a. Liver drained by hepatic veins

    b. Hepatic veins empty into inferior vena cava

E. Fetal Differences

1. Reason - mother's circulation handling some needs

    a. Gas exchange - lungs not needed

    b. Digestion & absorption - digestive tract not needed

    c. Excretion & fluid balance - kidneys not needed

2. Unique structures

    a. Placenta

        - Extraembryonic structure - against uterine wall
        - Formed by fetal capillaries surrounded by pools of maternal blood against
        - Maternal / fetal exchange organ

b. Umbilical arteries - within umbilical cord

- Branch from fetal internal iliac arteries
- Carry all fetal blood to placenta

c. Umbilical vein

- Returns blood from placenta to fetus
- Enters liver via portal vein
- After birth - solidifies into round ligament

d. Ductus venosus

- Bypass vessel around liver to inferior vena cava
- Mother's liver determines metabolic needs

e. Foramen ovale

- Passage through interatrial septum
- Much blood from right directly into left atrium
- Lungs only need enough blood to develop
- After birth - seals over into fossa ovalis

f. Ductus arteriosus

- Interconnecting vessel from pulmonary trunk to aortic arch
- Prevents even more blood from reaching lungs
- After birth - solidifies into ligamentum arteriosum

VASCULAR PHYSIOLOGY

Principles of Fluid Movement Through Tubes

A. Basic Principles

The five principles in the following chart are important for an understanding of several blood circulatory phenomena - namely, how & why it . . .

- Flows
- Is pressurized
- Undergoes variations in different parts of system

NAME	MEANING	CAUSES / NOTES / BLOOD APPLIC.	EXAMPLE
Pressure	Force per unit area	Ventricular systole - creates. Blood vessels - sustain & modify. This pushes fluid through tube.	120 mmHg
Flow	Volume over time period	Pressure gradient. Ventricular systole - creates. Continual - not intermittent.	100 ml/sec
Resistance	Force opposing flow	Friction between fluid & tube. Variables - length, x-section area & viscosity.	60 mmHg
Viscosity	Fluid's own resistance to flow	Degree of difficulty molecules have sliding over one another. RBC's main factor.	4.5 (H_2O is 1.0)
Velocity	Distance over time period	Speed of fluid. Flow is <u>amount</u> moving.	10 cm/sec

B. Relations

Examples of influences of above principles on each other.

1. Flow & pressure

    a. Change in <u>opposite</u> directions

b. Change proportionately with influencing cause

c. Neither can change independently

2. Resistance

a. Flow changes in opposite direction

b. Pressure changes in same direction

3. Velocity

a. V = F / A [Velocity = Flow / X-sectional Area]

∴ Velocity affected by fluid flowing into smaller or larger tube

- Decreases from smaller to larger*
- Increases from larger to smaller

*Analogous to water slowing down when flowing from stream into a lake

b. Keep in mind the number of vessels

- Blood goes from one larger to many smaller arterial branches - pooling effect
- If one larger to only one smaller, changes would be different

Arterial Phenomena

A. Blood Pressure (BP)

1. Concept

a. Pressure exerted by blood on vessel walls in closed system

b. Originally produced by ventricular systole

c. Vessel resistance & blood viscosity contributors

2. Amount - in systemic

    a. 120 / 80 mmHg in men

    b. 110 / 70 mmHg in women

    c. Measured at brachial artery

    d. Pulmonary pressure 20% of aortic

3. Systolic

    a. First, higher, amount - 120 in 120 / 80

    b. Reflects actual force of blood from left ventricular systole

    c. Causes expansion of aorta

        - From its elasticity
        - Force of about 180 mmHg
        - Reduced to 120 mmHg in brachial

4. Diastolic

    a. Second, lower amount - 80 in 120 / 80

    b. Produced by <u>elastic recoil</u> of artery

        - Force applied by arterial wall upon blood
        - Force came from stretch during systolic

    c. Less than systolic due to energy dissipation

5. Sequential effects - perpetuation

    a. Diastolic force pushes blood farther away from heart

        - This direction offers less resistance
        - Systolic / diastolic phenomena repeated in next section of artery
        - Phenomena repeated even farther along vessel & its

branches

b. Cycle continually repeated due to more blood replacing first increment, & so on

c. Blood flow is steady, though, flowing continuously, despite seemingly discrete increments passing through from pulsations

6. Measurement *[more details in lab]*

a. Sphygmomanometer utilized

b. Cuff originally compresses brachial artery

- Force must exceed systolic pressure
- Flow blocked

c. Pressure released slowly

- Sound heard when blood begins pulsing through - pressure reading is systolic
- Sound disappears when cuff no longer presses against brachial - reading is diastolic

7. Interpretation

a. Despite theoretical normal values, pressure may be somewhat higher or lower

b. Normal pressure is an individual situation

c. Changes over time are of great importance

8. Variations

a. Recall pressure drop as blood moves farther from heart

b. Examples of changes, using average of systolic & diastolic

- Aorta - 90 mmHg
- Large trunk vessels - 90 mmHg

- Arterioles - 30 mmHg
- Capillaries (venule end) - 12 mmHg
- Right atrium - 0 mmHg

c. Reason for decline is pressure gradient

9. Hypertension

a. High blood pressure

- >140 / 90 mmHg
- Severe if >180 / 115 mmHg
- Higher normal for those over 60 yrs.

b. Consequences of increased stress

- Vessels - atherosclerosis, hemorrhage & stroke
- Heart - ventricular failure & infarction
- Kidneys - renal failure

c. Causes

- Primary - only cardiovascular related - e.g.
  - Arteriosclerosis - hardening of arteries decreases elasticity & increases resistance – systolic up/diastolic down
  - Sympathetic nervous disfunction
  - Renin-angiotensin disfunction
- Secondary - non-cardiovascular related - e.g.
  - Kidney diseases
  - Hyperthyroidism
  - Cushing's syndrome

- Alcoholism

10. Hypotension

    a. Postural cause typical – e.g. sudden standing

    b. Usually from sympathetic nervous effects

        - Sympathetic inhibiting drugs
        - Postural (orthostatic) – sudden standing

B. Pulse

1. Concept - pulsation of artery
2. Cause

    a. Pressure wave from expansion & recoil

    b. Ventricular systole ultimate cause

3. Same as heart rate
4. Measurement

    a. Apical

        - Taken at chest wall
        - Heart's apex hits wall
        - Most direct method, but no more accurate

    b. Radial - wrist

    c. Carotid - neck

    d. Inguinal - groin

C. Pulse Pressure

1. Concept - numerical difference between systolic & diastolic pressures

2. Relationship with pulse - this is cause of pulse

3. Significance - sometimes better indicator of condition than BP . . .

    e.g. - 140 / 100 could be normal, since pulse pressure is still 40 (same as in 120 / 80)

D. Governing & Influencing Factors

1. Elastic arteries

    a. Stretch with force from ventricular systole

    b. Keep pressure high enough during diastole

    c. Perpetuate phenomenon away from heart

2. Muscular arteries

    a. Maintain pressure & flow to arterioles

    b. Variable constriction & dilation of muscular tunica media

3. Arterioles

    a. Exert final selectivity on pressure & flow

    b. Precise variations to maintain sufficient capillary exchanges between blood & tissue fluid

E. Variables

1. Cardiac output

    a. Increased CO will elevate pressure

    b. All other variables must be unchanged

2. Peripheral resistance

    a. Selective constriction or dilation in smaller arteries &

arterioles - pressure & flow effects

b. Significant influence on venous return - thus, chief determinant of EDV

3. Blood viscosity

a. If too great (or little) friction in vessels increased (or decreased)

b. Direct proportionate effect on BP & peripheral resistance

4. Blood volume

a. Too much overstretches heart & arteries - hypertension results

b. Too little decreases CO severely

- Causes hypotension
- Result would be shock - from brain effects

5. Arterial elasticity *[covered above]*

Capillary Phenomena

A. Pressure

Pressure drops from pooling effect *[covered above]*

- Not due to smaller diameter - this should cause rise in pressure
- Greater number than arterioles feeding them, with greater collective blood capacity

B. Exchanges with Tissue Fluid

1. Pressure differences

a. Arteriolar end - 30 mmHg

b. Venule end - drops to 12 mmHg

2. Colloid osmotic pressure

    a. Attraction of water from surrounding tissue fluid by blood's impermeable proteins

    b. Amount - 25 mmHg

3. Diffusion exchanges

    a. Arteriolar end

        - BP above colloid osmotic pressure
        - Permeable materials diffuse out of blood into tissue fluid

    b. Venule end

        - BP below colloid osmotic pressure
        - Metabolic wastes, hormones, etc., diffuse into blood from tissue fluid

C. Control

1. Primary

    a. By selective constriction or dilation of metarterioles & precapillary sphincters
    b. Can counteract general change in BP throughout body due to cardiac or other effects

2. Blood viscosity

    Influenced by concentration of globulins & albumins

        - Colloid osmotic pressure would be varied
        - Excessive changes would affect efficiency of diffusion exchanges

D. Vasomotion

1. Concept - intermittent flow through capillaries

2. Cause - continual variation of metarteriole & precapillary

sphincter action

3. Frequency - several times per minute, maximum

4. Purpose - customizes blood flow in individual tissues

5. Control - these tissues, via autoregulation *[details later]*

Venous

A. Changes

1. Pressure - drops

   a. Venules - 10 mmHg

   b. Venae cavae - 0 mmHg

   c. Variables - effects of compression from surrounding organs

2. Flow - decreases

   a. Veins larger than equivalent arteries - 4x cross-sectional area

   b. Sufficient number to create adequate venous return

B. Variable Influences

1. Ventricular systolic force

   a. Dissipated almost completely

   b. Other factors must be utilized for blood return

2. Ventricular diastolic vacuum

   a. Sucking action to heart

   b. Clear path exists from veins

      ■ A-V valves open

- Closed semilunar valves enhance effect

3. Respiratory pump

   a. During inspiration venae cavae expand

      - Sucks blood into heart
      - From pressure drop in lungs causing equivalent effect

   b. Increased intra-abdominal pressure assists

      - Helps create pressure gradient
      - Affects most length of inferior vena cava

4. Gravity

   a. Inhibits venous return

   b. Causes pooling of blood & vessel inflation

   c. Especially a problem in lower extremities

5. Muscular massaging

   a. Helps counteract gravity effects

   b. Veins pass between skeletal muscles - contraction squeezes blood through

   c. Semilunar-type valves - 2 pockets

      - Prevent backflow - direct blood upwards
      - Strategically located in relation to muscles

6. Blood volume

   a. Systemic veins act as blood reservoir

   b. Contain 60% of total in circulation

      - Arteries have 15%
      - Capillaries have 5%
      - Heart & pulmonary circuit have 20%

c. Amount can be varied according to body's needs

Regulation

A. Basic Arteriolar Diameter Effects

1. General - overall principles now *[details below]*

2. Vasoconstriction

   a. Pressure increased

   b. Flow decreased

3. Vasodilation

   a. Pressure lowered

   b. Flow increased

B. Autoregulation

1. Need - local flow control

   a. Different tissues will independently determine their blood flow for varying needs

   b. Cause local vasoconstriction or vasodilation

2. Causative stimuli - the opposite of these could occur as well

   a. Decreased PO_2
   b. Increased PCO_2

   c. Buildup of lactic acid from muscle fermentation

   d. Temperature increase

   e. Osmotic pressure changes

3. Mechanisms producing correction

    a. Kinins

        - Group of polypeptides
        - Released by stimulated cells
        - Cause vasodilation - flow increased
        - Cause increased capillary permeability

    b. Metabolic wastes - direct feedback, causing vasodilation

4. Effects

    a. Increased flow exposes more blood to exchange surfaces to clear out metabolic stagnation

    b. Increased permeability enhances

5. Other factors

    More complicated than presented above

        - Long term flow adjustments possible
        - Number of vessels can increase or decrease

C. Vasomotor Center

1. Description

    [previously presented -- heart regulation]

    a. Vascular control primarily via sympathetic nerves to arterioles

    b. Receives input for decisions from several types of receptors

2. Basic sympathetic mechanisms

    a. Vasoconstriction - increased stimulatory impulses

    b. Vasodilation

        - Decreased stimulation

- Causes passive dilation - i.e. lack of active constriction

c. Atypical method for autonomic control - usually parasympathetic actively sends impulses to cause opposite effects from sympathetic

3. Tonal constriction

a. Continual vasoconstrictor impulses to maintain basal level

b. Variable over time

4. Variable distribution

a. General - not all parts of body equally affected

b. Skin - provides services form entire body

- Extra blood vessels for temperature control
  - Dilation dissipates excess heat
  - Constriction keeps blood deeper
- Extra blood vessels for BP regulation
  - Dilation releases excess pressure
  - Constriction keeps pressure higher

c. Digestive organs

a. Flow selectively decreased during stress responses

b. Not essential during emergency situation

5. Hypothalamic effects

a. Overall control of vasomotor center

b. Example - part of direction of emotional & sexual responses

6. Conscious & other effects

a. Cerebral cortex stimulates or inhibits vasomotor

b. Both conscious & unconscious levels

7. Pressoreceptor (baroreceptor) reflex control

a. Sense organs in some vessel walls

- Aortic arch
- Carotid sinus of internal carotids
- Some other nearby large arteries

b. Respond to stretch - communicate blood pressure feedback to vasomotor center

8. Chemoreceptor reflex control

a. Sense organs in some vessel walls

- Aortic bodies beside arch
- Carotid bodies beside internal carotids

b. Primarily monitor O_2 levels

- For breathing control
- Feedback to brain's breathing centers

c. Contribute lesser degree towards vasomotor control - correlate respiratory & cardiovascular

D. Chemical Control

1. General - less significant than autonomic & autoregulation

2. Hormonal & other regulatory substances

a. Vasoconstrictors

- Angiotensin & ADH (vasopressin) - other roles as well *[later -- excretory system]*
- Norepinephrine

b. Vasodilators

- Kinins
- Prostaglandins
- Serotonin
- Histamine

3. Ions

a. Vasoconstriction - calcium increase

b. Vasodilation - increase in any of several ions

- Potassium
- Magnesium
- Sodium
- Hydrogen

4. Others

a. Vasoconstriction - nicotine

b. Vasodilation - alcohol