Physiology of Circulation
Blood Circulation

• Three factors which influence the circulation of blood are
  1 - Blood flow
  2 - Blood pressure
  3 - Resistance
Blood Flow

• Blood flow; volume of blood which flows through a vessel, organ, or the body.
  – For the body it would be equal to cardiac output (CO).
  – Otherwise, blood flow is adjusted to immediate needs of tissues or organs.
Blood Pressure

• Blood pressure is the force of blood against the wall of a vessel (or heart).
  – Measured in millimeters of mercury (mm Hg.)
  – By convention refers to systemic arterial blood pressure. However, blood pressure can be measured at any point.
  – Differences in pressures provide for movement of blood
Resistance

• Resistance is the opposition to blood flow. It is mostly produced by the “rubbing” of blood against the wall of vessels.
  – The term “peripheral resistance” is used to refer to the resistance produced outside of the heart (by blood vessels).

• Three factors which influence resistance are:
  1 - blood viscosity
  2 - total vessel length
  3 - blood vessel diameter
Resistance - Blood Viscosity

• Blood viscosity refers to the blood’s flowing-ability or “stickiness.”
  – greater viscosity produces more resistance. Plasma and formed elements resist movement and more force is required to push the flood

• Blood viscosity is relatively stable. However, conditions such as polycythemia, extensive dehydration, and some anemias can influence blood viscosity and blood pressure.
Resistance - Blood Vessel Length

• The greater the total vessel length the more resistance.
  – The “rubbing” of blood against the walls of vessels produces resistance. The greater the distance the more resistance.

• Blood vessel length is relatively stable. However, gain and/or loss of weight can dramatically change total vessel length.
Resistance - Blood Vessel Diameter

• Most important mechanism for changing resistance; thus, blood pressure.
  – Fluid along the wall of blood vessels “rubs” against the wall and is slowed by friction (resistance). Fluid in the center of the vessel is not influenced by the wall and flows freely
  – Thus, smaller vessels offer more resistance (more wall surface area to volume of blood) than larger vessels (less wall surface area to volume of blood. Chemical and neural control of small vessels (arterioles) provides an immediate mechanism to adjust blood pressure.
Blood Flow, Pressure, and Resistance

• Blood flow is directly proportional to blood pressure.
  – If pressure increases, flow increases
  – If pressure decreases, flow decreases

• Blood flow is inversely proportional to peripheral resistance
  – If resistance increases, flow decreases
  – If resistance decreases, flow increases
Systemic Blood Pressure

• Blood flow is produced by left ventricular systole and pressure results because of peripheral resistance.

• Blood flow is from higher to lower pressure
  – highest in the aorta and major arteries (120mm Hg)
  – lowest in the venae cavae (0mm Hg.)
Arterial Blood Pressure

• Arterial blood pressure reflects
  – the elastic stretch (compliance or distensibility) and recoil of arteries. Pressure generated by heart is transferred into vascular pressure (kinetic energy)
  – CO (cardiac output) or volume of blood in elastic arteries
  – Ranges from about 120mm Hg to 40mm Hg (in small arterioles)
Arterial Blood Pressure (cont)

• Pressure produced by left ventricle is transferred to aorta (and other elastic arteries)
• Closure of aortic semilunar valve isolates blood from heart (left ventricle is repolarizing and quiescent period follows.
• As blood flows into distal vessels (back toward heart) arterial pressure drops.
• Diastolic pressure is lowest arterial pressure reached before heart begins another cardiac cycle.
Pulse Pressure

- Pulse pressure is the difference between systolic and diastolic pressure. Pressure surge can be palpitated as an arterial pulse.
  - PP = 120 - 80 or PP = 40mm Hg.
  - Arteriosclerosis will produce an increase

- Mean (average) arterial pressure (MAP) is the actual driving pressure during cardiac cycle. Differs from PP because diastole and systole are not of equal time intervals.
  - Determined by diastolic pressure + 1/3 of the pulse pressure
  - MAP = 80 + (1/3 x 40) or MAP = 93mm Hg.
Blood Pressure Maintenance

• Three major factors influencing BP are
  – cardiac output, peripheral resistance, and blood volume
  – Blood pressure = cardiac output x peripheral resistance (BP = CO x PR)

• Cardiac output = heart rate x stroke volume
  – heart rate adjusted by parasympathetic and sympathetic systems
  – stroke volume involves preload, contractility, and afterload
    • Stroke volume also includes blood volume which is maintained by the kidneys.
Short-Term Neural Control of BP

• Neural controls help maintain BP by
  – rerouting of blood as demands require it
  – adjusting vessel diameter (vasodilation and vasoconstriction) to maintain MAP

• Neural controls are mostly reflex arcs which involve baroreceptors, the vasomotor center of the medulla oblongata, and vascular smooth muscle
  – vasomotor center controls vascular diameter
  – cardiac center adjusts cardiac output
  – Both centers make up the cardiovascular center
Vasomotor Center

• Sends impulses via sympathetic system to smooth muscle of blood vessels; mostly arterioles.
  – Vessels are always in a “state of excitation” called vasomotor tone.
  – Increased sympathetic stimulation results in vasoconstriction and increased BP
  – Decreased sympathetic stimulation results in return to basal levels and normal BP
Baroreceptors and BP

- Located mostly in carotid sinuses and aortic arch (also distributed in elastic arteries of neck and thorax)
  - carotid sinus is located in internal carotid artery which serves as major blood route to brain.
  - Increased arterial pressure stimulates increased neural flow from baroreceptors to the
    - vasomotor center. The vasomotor center is inhibited. Thus, vascular dilation occurs and BP is reduced.
    - cardiac center where parasympathetic activity is promoted (and sympathetic is inhibited). Thus, heart rate slows (and the increased force from sympathetic stimulation is reduced)
Chemoreceptors and BP

• Chemoreceptors are located in the carotid bodies (located by carotid sinus) and the aortic bodies (in aortic arch).

• Chemoreceptors monitor and are activated by
  – a drop in pH or blood oxygen
  – an increase in carbon dioxide
  – \( CO_2 + H_2O \rightarrow H_2CO_3 \rightarrow HCO_3^- + H^+ \)
  – Sends impulses to vasomotor center and reflex constriction occurs
  – Rise in BP increases return to heart and lungs thus modifying pH, oxygen, and carbon dioxide levels.
Short-Term Chemical Control of BP

- Chemical controls which help maintain BP
  - **Adrenal medulla** releases epinephrine and norepinephrine. E and NE have vasoconstriction effect. E increases cardiac output and rate.
  - **Antidiuretic hormone (ADH)** released by posterior pituitary regulates water reabsorption by the kidneys
  - **Angiotension II** is produced when the kidneys release renin. Angiotension is a powerful vasoconstrictor
  - **Endothelium-derived factors** include endothelin and nitric oxide (NO). Endothelin is released in response to slow blood flow and is vasoconstrictor. NO is released in response to high blood flow and results in vasodilation (thus, reduction of pressure).
Long-Term Regulation of BP

• Kidneys maintain blood volume
  – Blood volume is essential in maintaining CO

• Renal control (long-term) maintains BP by
  – altering the rate at which the filtrate is formed
  – renin-angiotensin mechanism
  – renin converts angiotensinogen into angiotensin I which is converted into angiotensin II. Angiotensin II is a powerful vasoconstrictor and targets the adrenal cortex to release aldosterone. Aldosterone promotes the reabsorption of sodium ions, thus water follows osmotically.
Pulse

• Pulse is the blood’s pressure wave which is exhibited as the expansion and recoil of an elastic artery.
  – Pulse rate is easily measured by palpitation of an elastic artery.
    • Superficial arteries such as the brachial are used. (also include temporal, facial, common carotid, femoral, popliteal, posterior tibial, and dorsalis pedis arteries)
  – Pressure points (same as pulse sites) are used to stop bleeding
Measuring Blood Pressure

• Auscultatory (listening) method is commonly used to measure BP.
  – Involves use of stethoscope and sphygmomanometer (BP cuff).

• Sphygmomanometers may be of several types which include the mercurial, aneroid, and electronic.
Measuring Blood Pressure

– Place cuff “arrow” directly over brachial artery (palpitate).
– Place stethoscope directly over front of elbow (antecubital fossa). Closer to artery the more intense the sounds.
– Inflate to about 140mm Hg
– Loosen exhaust valve (2 - 3 mm Hg. sec)
– Listen for onset of sounds of Karotkov
– First sounds recorded as systolic pressure
– Sound termination is recorded as diastolic pressure
Hypotension

• Usually considered as BP of under 100mm Hg. Systole
  – individual differences are important in determination of hypotension.
  – usually considered to promote “long life”
  – chronic hypotension may be due to hypothyroidism, Addison’s disease (decreased adrenal cortex function), etc.
  – acute hypotension is life threatening. May be due to circulatory shock, surgical hemorrhage, etc.
Hypertension

• Sustained elevated BP of 140/90 or higher; with elevated diastolic as a more significant indicator.
Primary Hypertension

• 90% of people with hypertension
• Primary hypertension is where no significant factor is identified. Includes
  – diet (high sodium, saturated fat, cholesterol)
  – obesity (increased total length of blood vessels)
  – age (usually an increase with age, starts with 40)
  – stress (sympathetic)
  – smoking (nicotine enhances sympathetic and vasoconstriction)
  – race (more blacks than whites)
  – heredity
Secondary Hypertension

- 10% of people with hypertension
- Includes
  - excessive renin secretion by kidneys
  - hyperthyrodism
  - arteriosclerosis
Velocity of Blood Flow

• Highest in large arteries, slowest in capillaries, and speeds up again in veins.

• Velocity is inversely related to cross sectional area of blood vessels.
  – Slow velocity in capillaries supplies time for exchange to occur.
    • Aorta 2.5 cm² @ 40 - 50 cm/s
    • Capillaries 4500 cm² @ 0.03 cm/s
    • Venae cavae 8 cm² @ 10 - 30 cm/s
Capillary Blood Pressure

• Capillary blood pressure is about 40mm Hg proximally and 20mm Hg distally.
  – Promotes time for exchange (blood velocity is slow) and capillaries are very permeable
  – High pressure does not damage thin capillary wall
Venous Blood Pressure

- Venous blood pressure is about 20mm Hg proximally and 0mm Hg distally (right atrium).
  - Low pressure results because of effects of peripheral resistance
  - Two mechanisms that aid venous return are the muscular and respiratory pumps.
Aiding Venous Return
Muscular Pump

- Muscular pump promotes venous return by the “milking” action exerted upon peripheral veins which have one-way valves.
  - standing and inactivity promotes blood pooling in the ankles and feet; thus, reduces venous return and a decrease in blood pressure results.
  - Orthostatic hypotension (postural hypotension); abnormally low blood pressure produced when an individual assumes the standing position.
    - Mostly seen in elderly and sign of aging sympathetic nervous system. Slower postural changes rectify.
Aiding Venous Return
Respiratory Pump

• Inhalation causes an increase in abdominal pressure and a decrease of thoracic pressure - diaphragm movement is downward.
  – Thoracic pressure decreases
  – Abdominal pressure increases
  – Thus, promotes blood flow toward the heart
Intrinsic Control of Blood Flow

• Tissues and organs have local control through the metabolic and myogenic controls.

• Serves to promote blood flow to areas of need.
Myogenic Control of Blood Flow

• Vascular smooth muscle responds to changes in pressure
  – stretch causes vasoconstriction and increased tone
  – reduced stretch causes vasodilation
  – Provides continued blood delivery to tissue
Metabolic (Chemical) Control of Blood Flow

• Tissues respond to declining levels of oxygen, increased carbon dioxide levels, and decreasing pH.
  – Chemicals such as nitric oxide (NO), histamines, lactic acid, etc. promote local vasodilation and relaxation of capillary sphincters.
  – Hyperemia is increased blood flow in part of the body. Especially seen in the inflammatory response.
Fluid Movements

• Movement of fluid across the capillary is due to dynamics between hydrostatic and osmotic pressures.
  – Hydrostatic pressure is the pressure of fluid against a wall. Or, blood hydrostatic pressure is blood pressure.
  – Osmotic pressure is indicated by a solution solute concentration. Water moves across a selectively permeable membrane from a region of higher concentration to lower concentration. Concentration of water is determined by solute concentration.
Capillary Fluid Movement

- Blood hydrostatic pressure (HPc)
- Blood osmotic pressure (OPc)
- Interstitial fluid hydrostatic pressure (HPif)
- Interstitial fluid osmotic pressure (OPif)
Arterial End of Capillary

- Net blood hydrostatic pressure at the arterial end of the capillary is approximately 35mm
  - $35 (\text{HP}_c) - 0 (\text{HP}_{if}) = 35$
- Net osmotic pressure at arterial end of capillary is 25mm
  - $26 (\text{OP}_c) - 1 (\text{OP}_{if}) = 25$
- Thus, net filtration pressure (NFP) or the driving force outward is
  - $35 - 25 = 10\text{mm}$
  - $\text{NFP} = (\text{HP}_c - \text{HP}_{if}) - (\text{OP}_c - \text{OP}_{if})$
Venous End of Capillary

- Net blood hydrostatic pressure at the venous end of the capillary is approximately 17 mm
  - \(17 \ (HPC) - 0 \ (HPf) = 17\)

- Net osmotic pressure at venous end of capillary is 25 mm
  - \(26 \ (OPc) - 1 \ (OPf) = 25\)

- Thus, net filtration pressure (NFP) or the driving force inward is
  - \(17 - 25 = -8\) mm
  - \(NFP = (HPC - HPf) - (OPc - OPf)\)
Circulatory Shock

• Inability of blood delivery flow to meet the demands of tissues. Includes
  – hypovolemic shock
  – vascular shock
  – cardiogenic shock
Hypovolemic Shock

• Hypovolemic shock due to hemorrhage, excessive fluid loss as might occur with severe diarrhea or vomiting or extensive burns.
  – One of first signs is usually increased heart rate as a sign of compensation for decreased stroke volume
Vascular Shock

• Vascular shock is due to abnormal dilation of vascular system. Most commonly due to anaphylaxis, neurogenic shock (ANS failure), and septicemia (most bacterial toxins are powerful vasodilators)
Cardiogenic Shock

• Due to failure of the heart.
  – Cardiac output cannot maintain adequate blood flow to tissue.