Cardiac Hemodynamics – Part 2
Blood Pressure Regulation
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The Blood Vessels

- Arteries take blood away from the heart
  Elastic walls and thick layers of vascular smooth muscles
  - Act as pressure reservoir
- Veins take blood back to the heart
  - Thin walls of vascular smooth muscles
  - Act as volume reservoir

Exchange Takes Place in the Capillaries

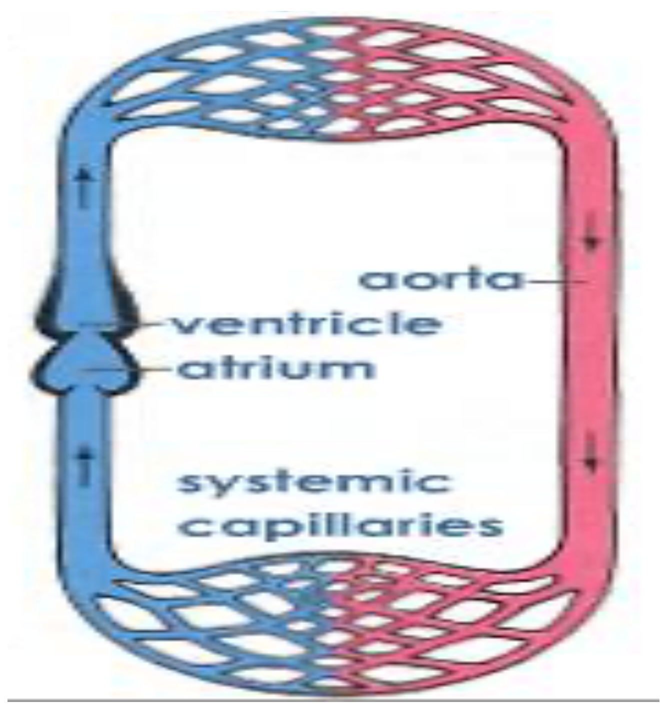
- Absence of vascular smooth muscle and elastic tissue reinforcement in capillaries facilitates exchange
  - One cell-thick layer of endothelial cells on basal lamina

Angiogenesis

- Development of new blood vessels
  - Necessary for normal development
  - Wound healing and uterine lining growth
  - Enhances heart and skeletal muscle blood flow
  - Needed for malignant tumor growth

Blood Pressure

- Pulse pressure = systolic P – diastolic P
- Valves ensure one-way flow in veins
- Mean Arterial Pressure (MAP) = diastolic P + 1/3(systolic P – diastolic P)
- Blood pressure is estimated by sphygmomanometry
- Hypotension is lower than normal MAP
- Hypertension is higher than normal MAP

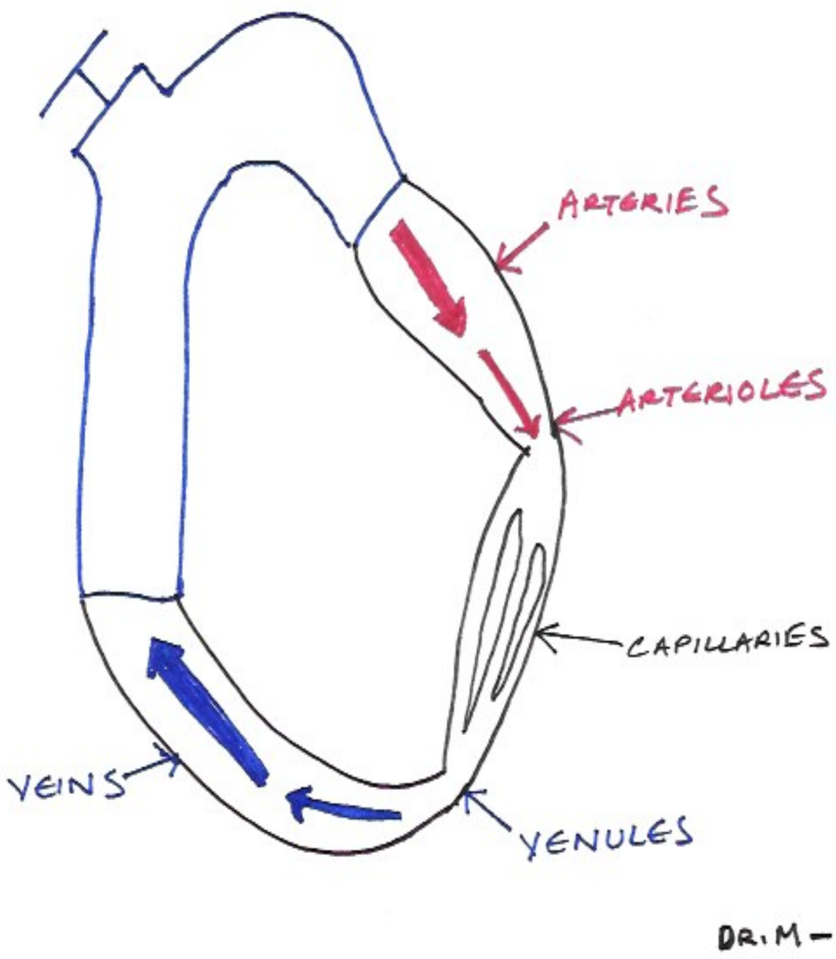


Simplified Analogy of Water Faucet – Fluid Dynamics

- Increased pressure through the hose >>>>> increased volume of flow
- Increased resistance in the hose >>>>>> decreased volume of flow
- Cardiac term for flow = Cardiac Output **CO**
- Cardiac term for blood pressure = **P**
- Cardiac term for resistance = Peripheral Resistance **PR**
- Blood flow = **F**

F = △ P / Resistance

Flow is inversely proportional to the pressure over resistance



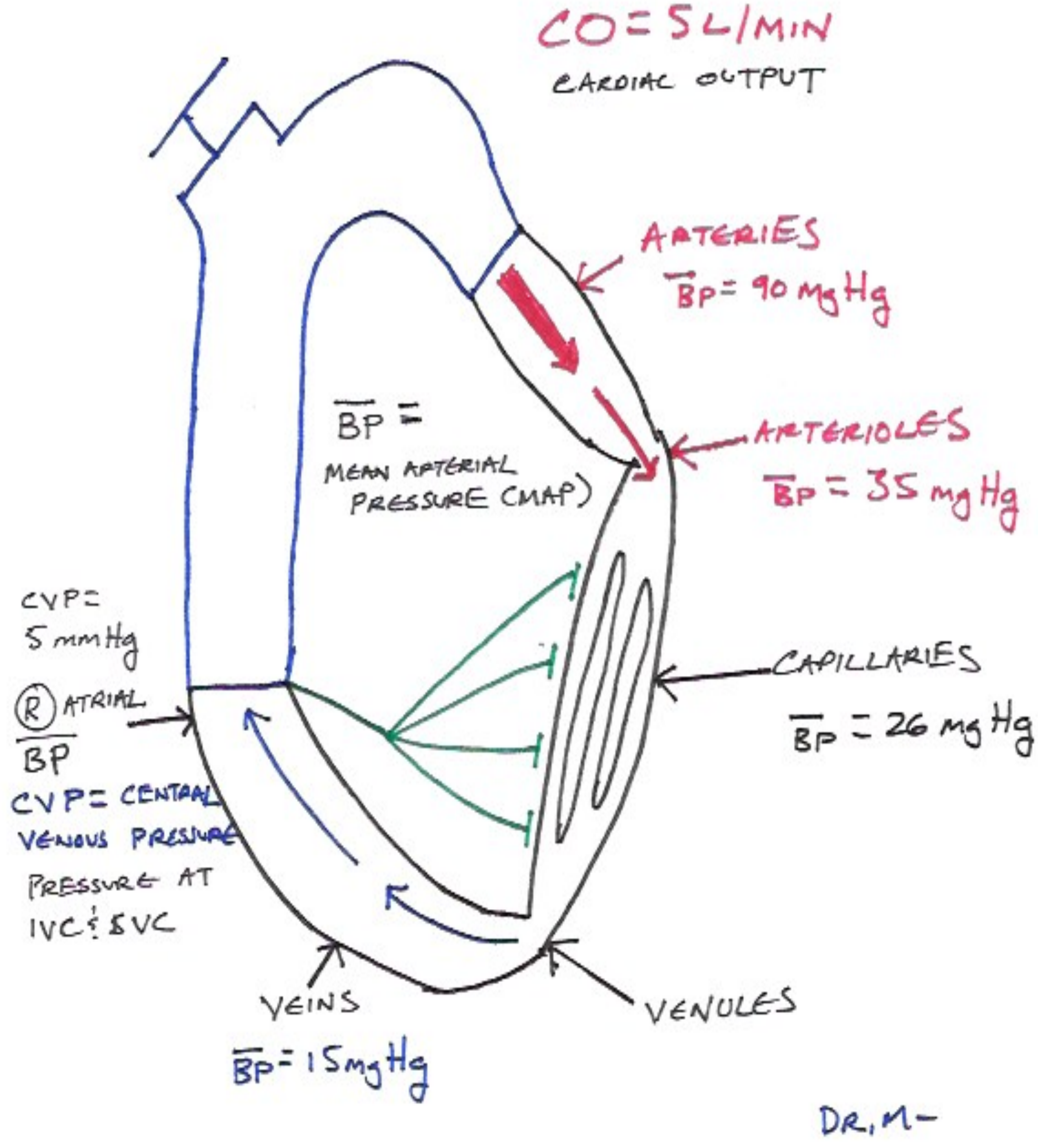
Arterial System & Arterial Blood Pressure

Blood flow equation **F = △ P / R**

Rearranging the blood flow equation **△ P = F X R**

M.A.P. Mean Arterial Blood Pressure =

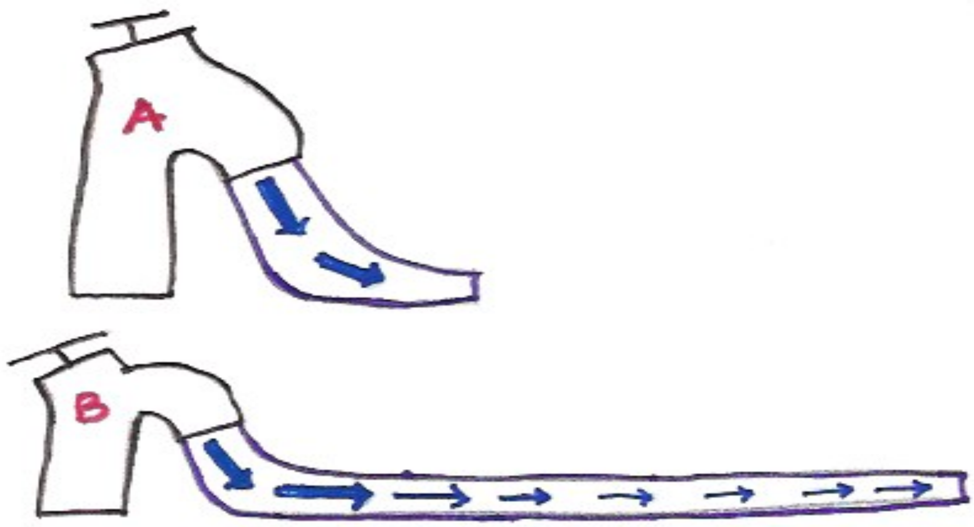
C. O. Cardiac Output X T.P.R. Total Peripheral Resistance



CO = 5L/MIN
CARDIAC OUTPUT
ARTERIES
BP = 90 mgHg
ARTERIOLES
BP = 35 mgHg
BP =
MEAN ARTERIAL PRESSURE (MAP)
CVP = 5 mmHg
(R) ATRIAL BP
CVP = CENTRAL VENOUS PRESSURE
PRESSURE AT IVC & SVC
CAPILLARIES
BP = 26 mgHg
VEINS
BP = 15 mgHg
VENULES
DR. M-

Two faucet analogy and fluid transfer

- The farther away we get from the faucet, the lower the pressure
- If you were to poke holes in the hose, the water would gush out close to the faucet and trickle out far away. The pressure will drop more and more the farther we get away from the hose.
- The blood pressure in the capillaries is higher than in the veins.



- Clinical Application – Distention of the jugular veins means and increase in Venous Blood Pressure (VBP)
- An increase venous pressure is usually due to right sided CHF

Continuous blood flow through the vessels

- There is a continuous blood flow through the vessels even though the ventricles only eject blood intermittently.
- This is due to the elasticity of the large arteries
    - The large arteries expand and recoil like stretched rubber bands.
    - This elasticity tends to dampen the increase in blood pressure during systole, while sustaining the blood pressure during diastole.
    - Thus, there is a smoother, less pulsatile flow of blood downstream

Resistance to blood flow

- The total hindrance to the flow of blood is called **TPR or Total Peripheral Resistance -** This is also called vascular resistance
- **Four Things determine TPR of vascular resistance**
    - **Arteriolar constriction**
    - **The degree of vascular stenosis**
    - **Total blood volume – TBV**
    - **Blood viscosity**

Arteriole Constriction and TPR

- The arterioles are smaller muscular arteries which is why they are called resistance vessels
  - Anatomy review – Only the small arterioles have smooth muscle around them and can constrict and dilate. The large arteries and veins do NOT have smooth muscle. They have elastic fibers which can stretch and recoil.
- As some arterioles constrict, other will dilate. This acts to direct the blood from inactive regions of the body.
  - Consider – exercise
- Remember – **Average Blood Pressure = C. O. x Increased TPR**
- Think about the faucet analogy – If you constrict the hose, this will do two things:
  - Increase the resistance after the constriction
  - Increase the pressure before the constriction
- Average arterial blood pressure = cardiac output x total peripheral resistance
  - If there is no resistance, than the blood pressure stays the same
  - What if you increase TPR?

Sympathetic >>>>>>> Overall Vascular >>> Increased TPR >>> Increased Arterial
Motor Neurons Vasoconstriction BP Average

I.E. if the blood vessels constriction is raised, it raises the blood pressure

Arteriole Constriction and TPR

- What if you decrease TPR?

Increased Overall Vascular >>>>> Decreased TPR >>> Decreased
Arterial Vasodilation
BP Average

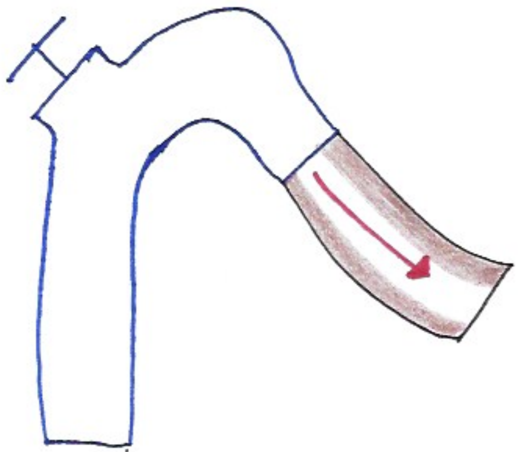
I.E. if the blood vessels dilation is raised, it lowers the blood pressure

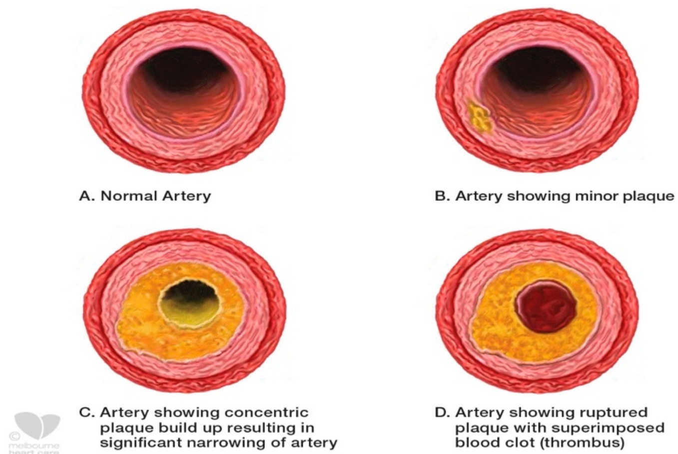
- What would be an example of something that would massively dilate all the blood vessels of the body?
  - Anaphylactic Shock – An allergic reaction can release histamine, which dilates the blood vessels of the body.
  - The massive overall dilation would lower blood pressure

The Degree of Vascular Stenosis and TPR

- Stenosis is a narrowing or occlusion due to atherosclerosis plaquing

Stenosis >>>>> Increased TPR >>>>> Increased Average Arterial Blood Pressure





Total Blood Volume – TBV

- Normal total blood volume = 8% of body weight
- Hypervolemia
    - Example – Salt and water retention

Increased TBV >>>>>> Increased TPR >>>>>> Increased Average Arterial BP

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    - Rx: Diuretics
- Hypovolemia
    - Example – Hemorrhage

Decreased TBV >>>>>> Decreased TPR >>>>>> Decreased Average Arterial BP

Viscosity of the blood

- Determined by the relative proportion of RBC in the blood
- HcT – Hematocrit
    - Percentage % of packed cell volume (PCV)
    - Decreased HcT = decreased % PCV

Decreased Viscosity >>>> Decreased TPR >>>> Average Arterial BP

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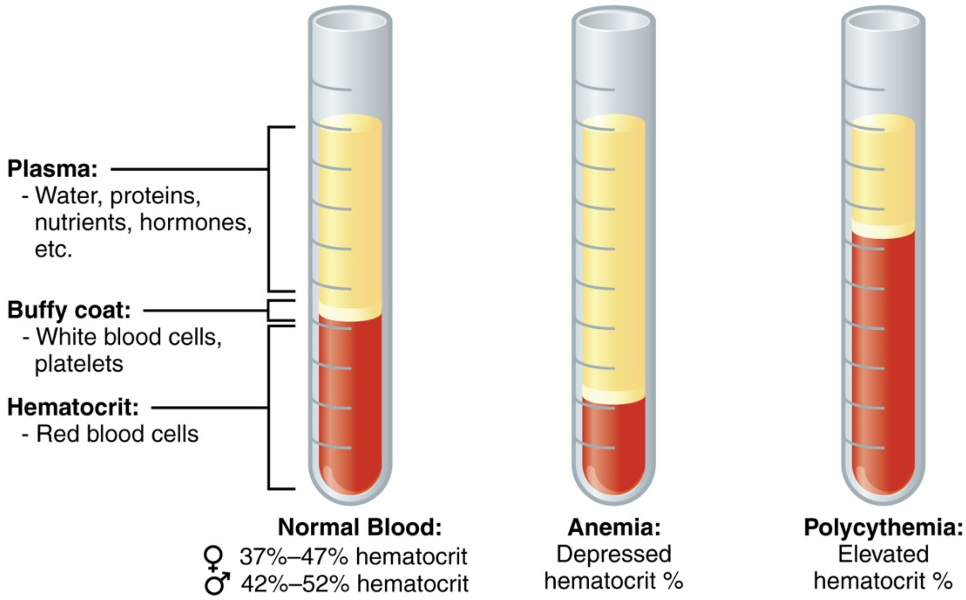
    - Increased HcT = Increased % PCV

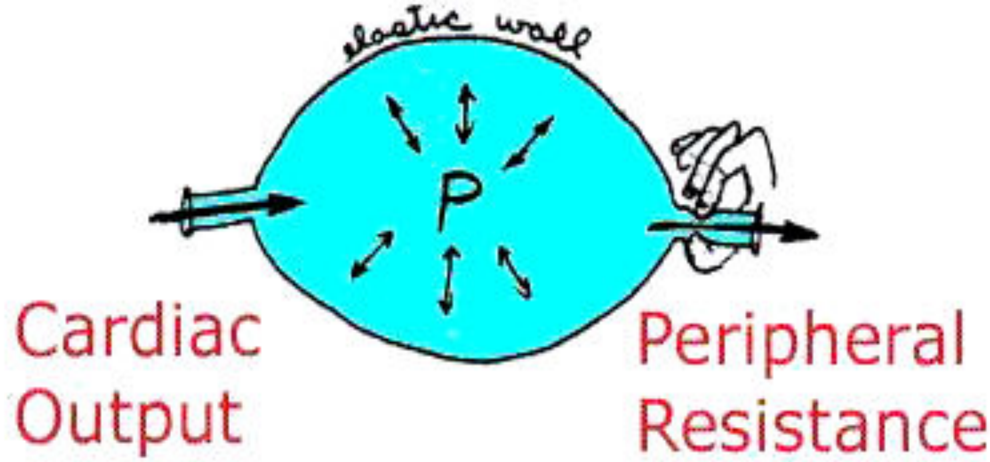
Increased Viscosity >>>> Increased TPR >>>> Average Arterial BP



Arterial Blood Pressure

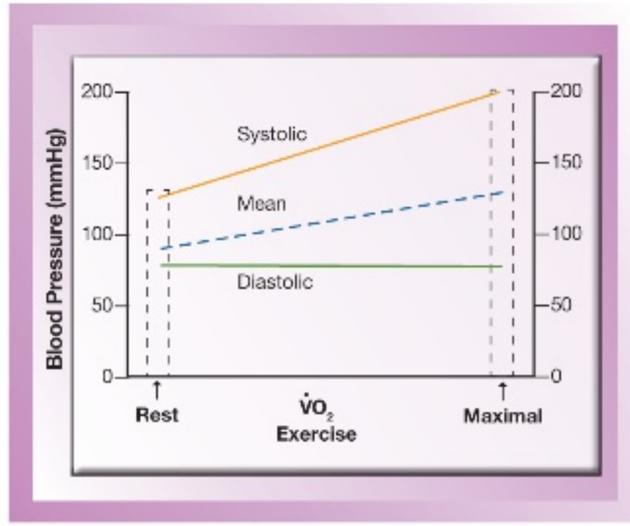
- Normal systolic and diastolic values
    - Systemic circuit = $\frac{120}{75}$ mm Hg
        - Acceptable Ranges = $\frac{90}{60}$ mm Hg to $\frac{140}{90}$ mm Hg
    - Pulmonary circuit = $\frac{25}{10}$ mm Hg
- The systolic blood pressure is determined mainly by the cardiac output
- The diastolic blood pressure is determined mainly by the peripheral resistance

Systolic BP from CO
Diastolic BP from TPR



Arterial Blood Pressure

- Factors Affecting Blood Pressure
  - Age, Exercise, Stress, Race, Gender, Drugs, Obesity, Disease
- Blood pressure during strenuous exercise
  - 173 / 83 mm Hg
  - Systolic pressure increases greater than diastolic pressure due to:
    - Increased contractility of heart and increased stroke volume
    - Vasodilation in the exercising muscle results in more blood draining from the arteries through the arterioles into the capillaries, which minimizes the change in diastolic pressure.



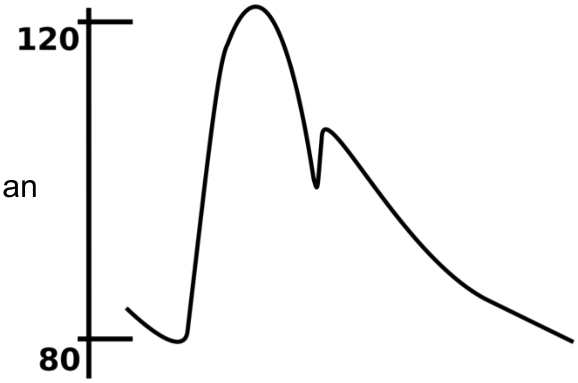
Normal responses to blood pressure during exercise

Arterial Blood Pressure

- Pulse pressure (PP)
  - SBP (Systolic BP) – DBP (Diastolic BP) = PP
  - SBP – DBP = PP
    - $\frac{120}{75}$ = 45 mm Hg
  - It reflects the driving pressure that effectively pushes the blood through the vessels.
  - This tells us the strength of the ventricle contraction or stroke volume
  - During strenuous exercise

    $\frac{160}{65}$ mm Hg Increased systolic is due to increased HR
Decreased diastolic is due to decreased TPR
    - During exercise, there is a widening of the pulse pressure, which shows the increased effort of the heart.
- Estimating the average systemic mean BP
  - Average arterial blood pressure = $\frac{1\ SBP + 2\ DBP}{3}$
  - Systole lasts .3 second and diastole lasts .5 second

$$\frac{120 + 150}{3} = \frac{270}{3} = 90$$

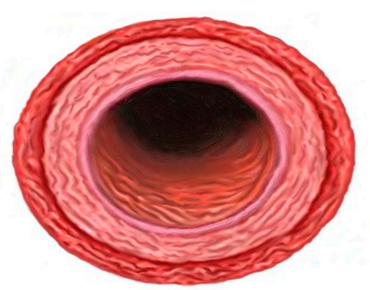


- Why does the average BP matter?
  - The function of the medulla is to maintain an average blood pressure

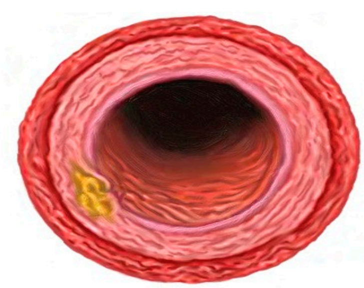
Pathophysiology of the Arterial Vessels

- **Arteriosclerosis**
  - Increased fibrosis of the arteries with age >>>> decreased elasticity
  - Increased SBP / increased DBP
- **Atherosclerosis**
  - Associated with the accumulation of fat, cholesterol and calcium in the inner walls of the blood vessels.
  - Called atherosclerotic plaque

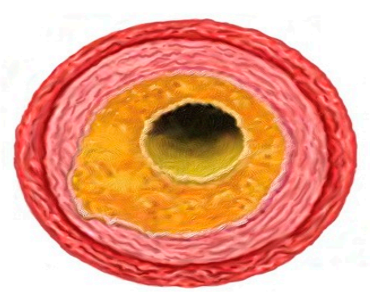
Stenosis of the lumen >>>>>> Increased vascular resistance to flow (TPR) >>>>>> increased arterial diastolic blood pressure (increased afterload)



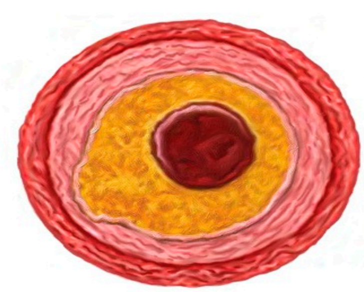
A. Normal Artery



B. Artery showing minor plaque



C. Artery showing concentric plaque build up resulting in significant narrowing of artery



D. Artery showing ruptured plaque with superimposed blood clot (thrombus)

Pathophysiology of the Arterial Vessels

- Complications of atherosclerosis
  - Increased probability of blood clot formation (thrombus)
  - Increased BP >>>>> increased probability of cerebral hemorrhage
  - Increased workload on the ventricles >>>>> CHF

- The development of atherosclerosis is related to:
  - Heredity, Obesity, Smoking, Lack of Exercise, Stress, Consumption of Saturated (animal) Fats
- The long term effects of exercise on arterial blood pressure

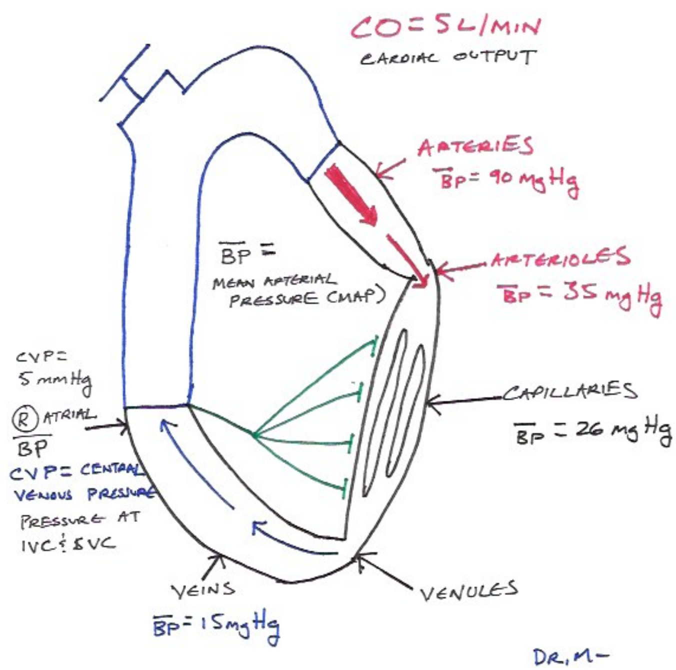
<u>After 10 Years of Exercise</u>

	Before	After
Heart Rate	78	59
Systolic	131	125
Diastolic	84	78

- Diagnostic evaluation
  - Arterial BP
  - Plasma cholesterol
  - Plasma LDL (low density lipoprotein)

Capillary Beds and the Lymphatic System

- The location where nutrients and waste products are exchanged between the bloodstream and the tissue fluid.
- Blood pressure in the capillaries
  - As the blood flows downstream, the pressure falls.
  - There is no pulse pressure downstream from the arterioles in the systemic circuit.



Capillary Beds

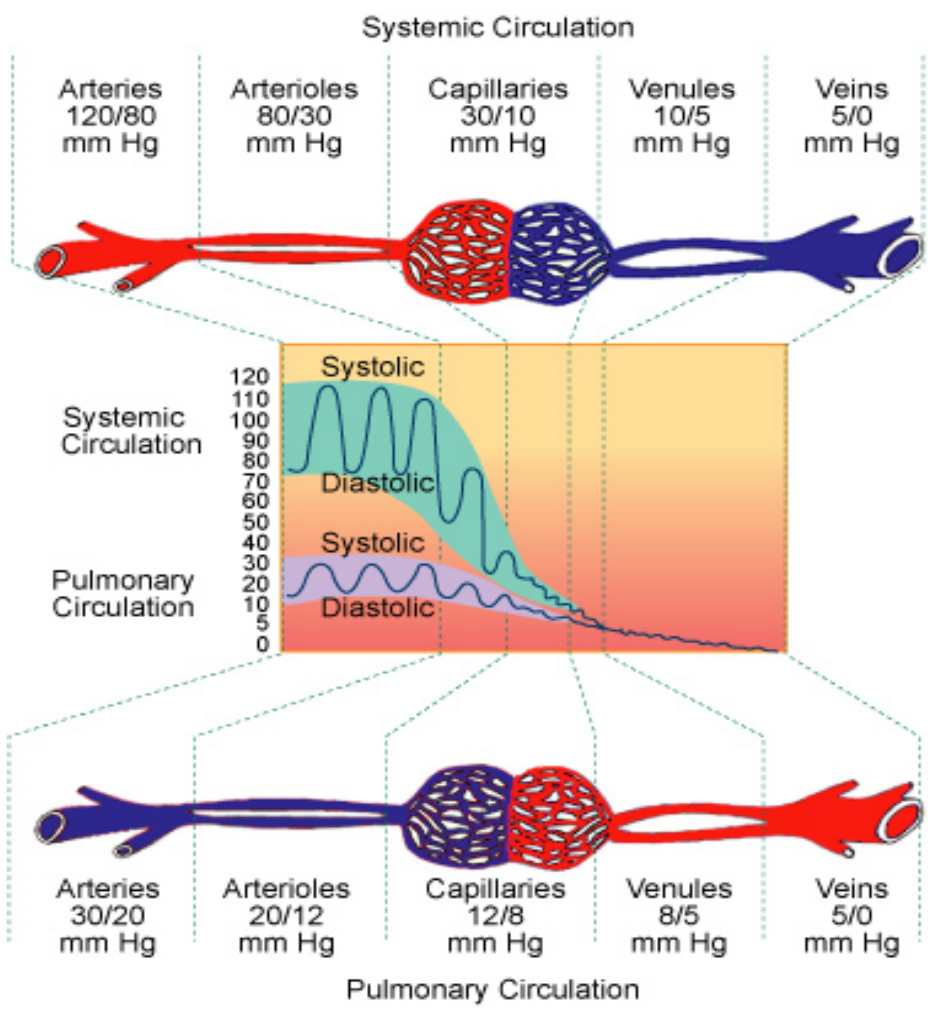
- Pressure Differences (with CO at 5 L/Min)
  - Average arterial BP = 90 mm Hg (120/75)
  - Average arteriolar BP = 35 mm Hg
  - Average capillary BP = 26 mm Hg
  - Average venous BP = 15 mm Hg
  - Average pressure of venae cavae = 5 mm Hg
    - This is called CVP – Central Venous Pressure

Factors affecting venous return (VR)

- Semilunar shaped one way vales the prevent backflow in the veins
- Sucking action of inhaling
  - Every time we inhale, it lowers the pressure in the chest
- Contraction of skeletal muscles
  - compresses and squeezes the veins, forcing blood forward
- Venous constriction

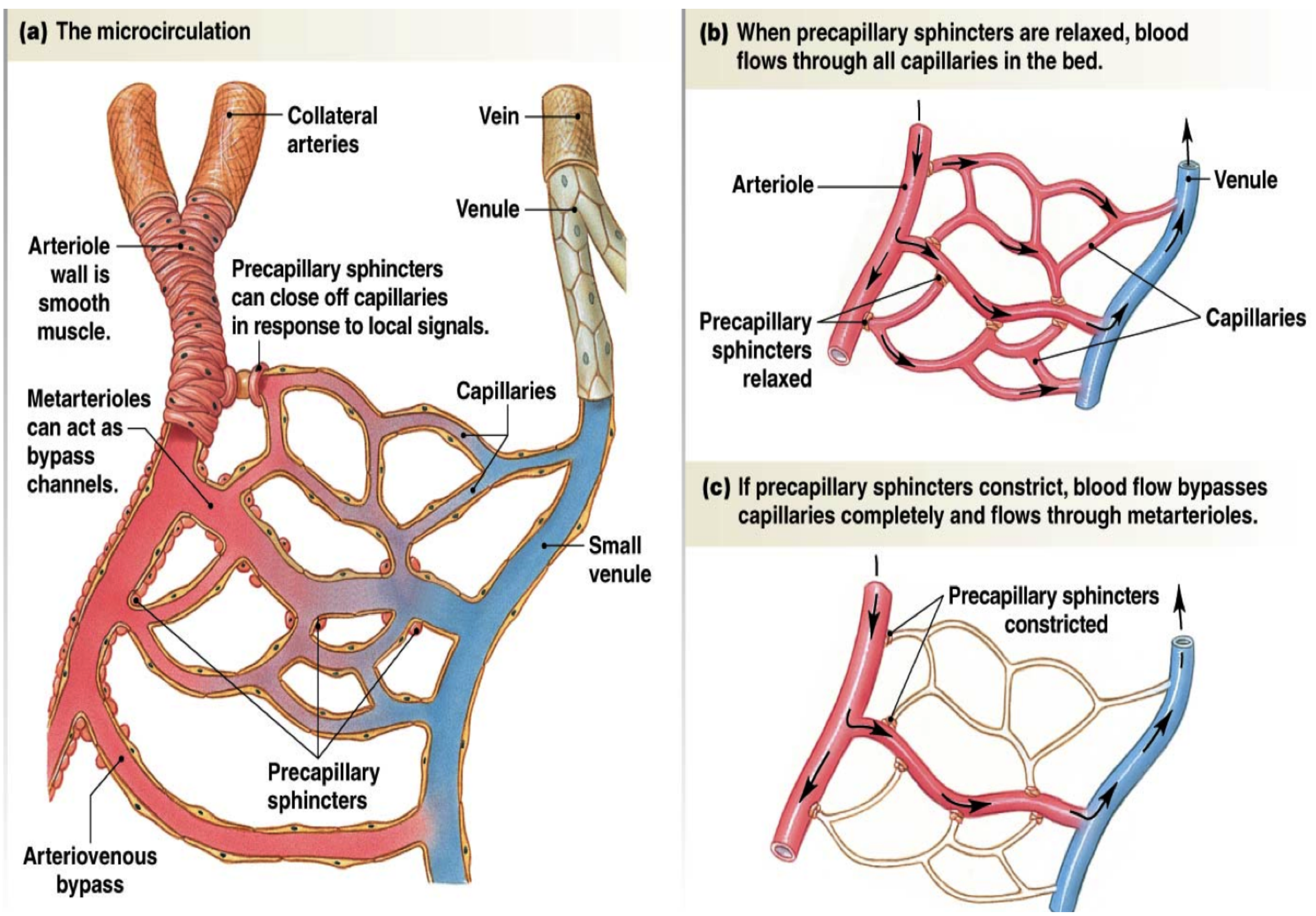
Velocity of blood flow

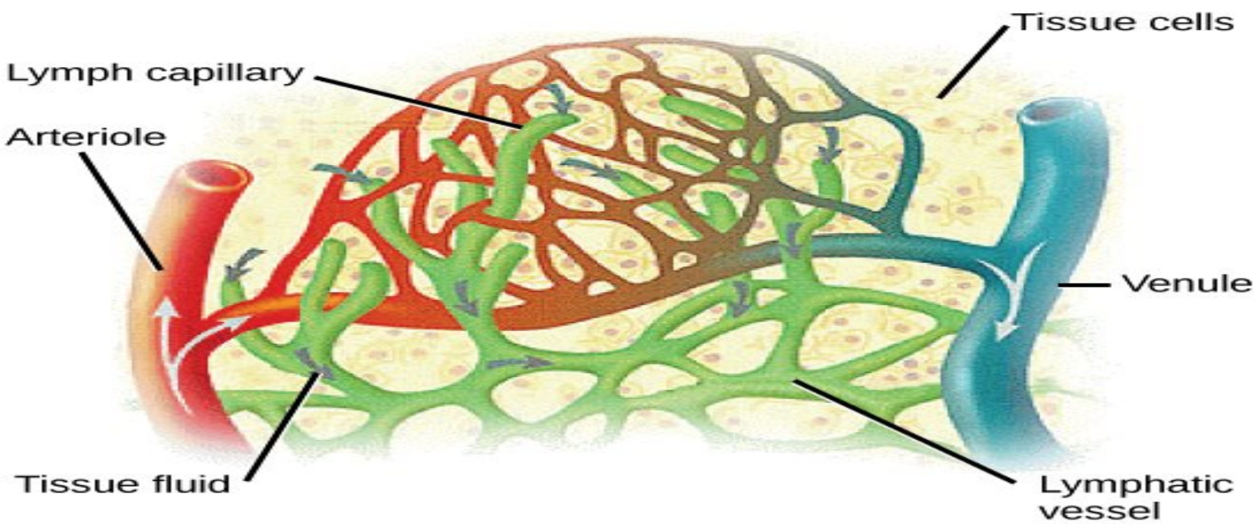
- While the total rate of flow is the same throughout the circulatory system (normal at rest is 5 L/min), the velocity of blood flow differs in different types of vessels.
  - Blood flows faster in the large conducting vessels – arteries and veins
  - Blood flows slowest in the narrow capillaries where the actual exchange of nutrients and waste products happens.
- These differences in the velocity of blood flow results from the different total cross-sectional areas in the different types of vessels.



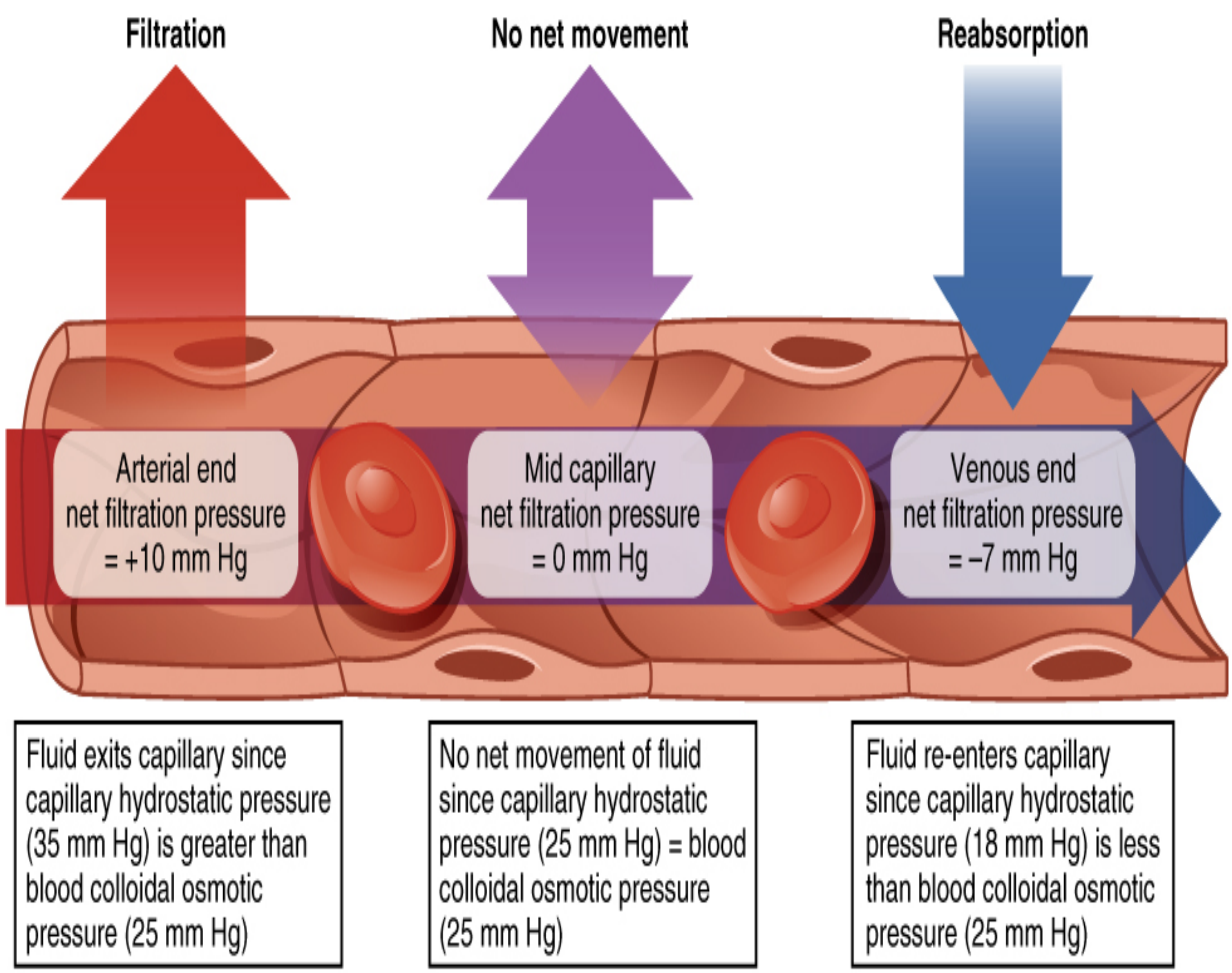
Microanatomy of the capillary bed

- The capillaries are narrow, delicate vessels composed of simple squamous epithelial (endothelial) cells.
- Pre-capillary sphincters are muscular valves that regulate blood flow through the capillary bed.
    - Capillary bed by-pass channels
- Metarterioles (Capillary By-Pass Channels)
    - Can divert blood from an arteriole directly to a venule, thus bypassing the capillary bed.
    - Since there is about 60,000 to 100,000 miles of blood vessels in the capillaries in the body, there is simply not enough blood to fill them all at once.
    - Thus, at any given time, the metarterioles are shunting the blood past most of the capillary beds of the body.





Tissue cells
Lymph capillary
Arteriole
Venule
Tissue fluid
Lymphatic vessel



Filtration
No net movement
Reabsorption
Arterial end net filtration pressure = +10 mm Hg
Mid capillary net filtration pressure = 0 mm Hg
Venous end net filtration pressure = −7 mm Hg
Fluid exits capillary since capillary hydrostatic pressure (35 mm Hg) is greater than blood colloidal osmotic pressure (25 mm Hg)
No net movement of fluid since capillary hydrostatic pressure (25 mm Hg) = blood colloidal osmotic pressure (25 mm Hg)
Fluid re-enters capillary since capillary hydrostatic pressure (18 mm Hg) is less than blood colloidal osmotic pressure (25 mm Hg)

Movement of solutes and water across capillary walls

- All solutes, except proteins, can simply diffuse into and out of the capillaries
- There are two factors that determine the movement
    - Capillary Blood Pressure (CBP)
        - Capillary hydrostatic pressure
        - Normal is 26 mm Hg
        - This pressure causes filtration of water <u>out</u> of the capillary
    - Plasma Colloid Osmotic Pressure (COP)
        - Normal is 25 mm Hg
        - This osmotic pressure results from the presence of non-diffusible proteins in the plasma
        - Most of these proteins are synthesized by the liver and secreted into the bloodstream
        - Most of the protein in the blood is albumin
- Proteins in the blood:
    - Albumin
        - Accounts for 60% of the plasma proteins
        - Maintains the plasma volume by drawing water into the bloodstream
    - Globulins
        - Accounts for 35% of the plasma proteins
        - Alpha and Beta globulins transport lipids and certain minerals through the bloodstream
        - Gama globulins are also called immunoglobulins or anti-bodies
            - They are synthesized by the lymphocytes
    - Blood clotting proteins
        - Accounts for 5% of the plasma proteins
        - Prothrombin and fibrinogen
        - Serum is blood plasma without the clotting proteins
        - Hemophilia – a genetic inability to synthesize blood clotting proteins.
- The net movement of water across the capillary walls
    - Net filtration pressure
        - Capillary BP – COP (colloid osmotic pressure)
        - Thus, there is a net pressure of 1 mm Hg forcing water out of the bloodstream.
        - This excess fluid (that is forced out of the capillaries) is returned back into the general circulation by lymphatic capillaries.

Pathophysiological Conditions

- **Edema**
  - An excess accumulation of tissue fluid
  - Systemic edema
  - Localized edema
  - Pulmonary edema
  - Abdominal edema (ascites)
- **Dehydration**
  - A reduced amount of tissue fluid >>>>> drying out and tissue death
- **Effects of blood pressure**
  - **Hypotension (Shock)**

Decreased Art. BP >>>> Decreased Capillary BP >>>>
Decreased filtration of water out of the capillaries >>>> Dehydration

  - **Hypertension**

Increased Art. BP >>>> Increased Capillary BP >>>>
Increased filtration of water out of the capillaries >>>> Edema

- **The effects of liver disease**
  - Types
    - Hepatitis
    - Cirrhosis
    - Starvation (protein deficiency in diet – Kwashiorkor
  - Development of Ascites

Decreased protein synthesis >>>> Decreased plasma proteins >>>>
Decreased COP (Colloid Osmotic Pressure) >>>>
Decreased diffusion of water back into capillaries >>>> Edema

The Venous System

- About 60% of the total circulating blood is within the veins at rest

VR – Venous Return

- The movement of the systemic blood to the right atrium
- Normal Venous Average BP = 15 mm HG
- Normal Right Atrial Average BP = 5 mm Hg
    - Called CVP – Central Venous Pressure
    - Distortion of the jugular veins reflects an increase in the venous blood pressure.
    - An increased venous blood pressure is usually due to right sided CHF
- Factors affecting venous return
    - Semilunar shaped valves to prevent backflow into the veins
    - Suction action of inhaling
    - Contraction of skeletal muscles
        - Compresses (squeezes) the veins
    - Vasoconstriction
- **Clinical considerations of venous return**
    - Most commonly occurs in the great saphenous veins of the legs and in the hemorrhoidal veins of the anal canal
    - Veins become distended with blood due to insufficient valves
    - Contributing factors
        - Extended standing, sitting or bed ridden
        - Obesity
        - Pregnancy

Cardiovascular Regulation

Cardiovascular Reflex Center

- The CV Reflex Center is in the medulla
- **Sensory Inputs**
    - **Baroreceptors**
        - Locations
            - Carotid Sinus – bulge in walls of carotids
            - Aortic Sinus – bulge in walls of aorta
        - The baroreceptors are mechanoreceptors that respond to changes in pressure (remember sleeper hold – below 60 mm Hg)
    - **Chemoreceptors**
        - Locations
            - Carotid bodies and Aortic bodies
        - The chemoreceptors respond to changes O_2, CO_2, H^+
    - **Higher Brain Centers**
        - Cerebral Cortex
            - Visualize – learning how to voluntarily influence your heart rate and blood pressure
        - Limbic System & Hypothalamus
            - Visualize – emotional effects on BP such as excitement, anxiety, depression
- **Motor Outputs**
    - Mediated by sympathetic and parasympathetic motor neurons
    - Effectors:
        - Heart >>>> change in cardiac output
        - Veins >>>> change in venoconstriction >>>> change in venous return
        - Arterioles >>>> change in vasoconstriction >>>> change in TPR

The Baroreceptor Reflex

- Visualize decreased systemic arterial blood pressure

Baroreceptors

Decreased BP >>>>>>>>>>>>>>>>> CV Reflex Center >>>>>
Generalized Sympathetic Response

- Sympathetic Responses
    - Increased Cardiac Output
        - Tachycardia (increased heart rate)
        - Increased myocardial contractility >>>> Increased Stroke Volume
    - Vasoconstriction >>>> increased venous return >>>> increased EDV (filling)
    - Generalized arteriolar vasoconstriction >>>> increased TPR

Average Arterial BP = Increased CO X TPR

The Chemoreceptor Reflex

- Decreased O_2 – hypoxemia
- Increased CO_2 – hypercapnia
- Increased H^+ - acidosis
- Sympathetic Responses
    - Increased Cardiac Output
        - Tachycardia (increased heart rate)
        - Increased myocardial contractility >>>> Increased Stroke Volume
    - Vasoconstriction >>>> increased venous return >>>> increased EDV (filling)
    - Generalized arteriolar vasoconstriction >>>> increased TPR

Intrinsic Control of Blood Flow

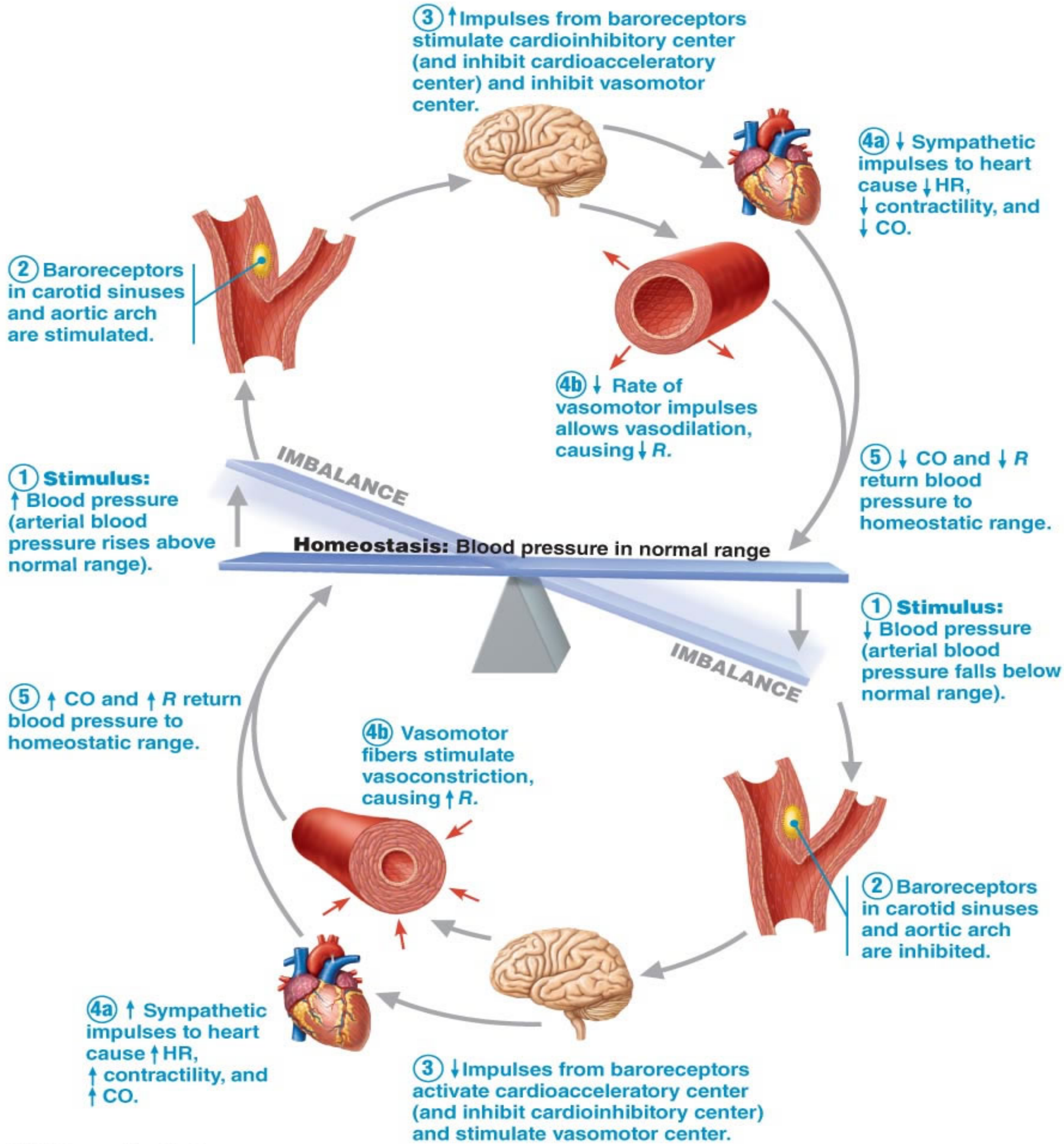
- Autoregulation
    - Called Active Hyperemia
    - Local change in the metabolic rate of a tissue causing local changes in blood flow
    - Mechanism of autoregulation
        - Local decrease O_2 (ischemia) >>>>>> local vasodilation
        - Local increase CO_2 >>>>>> local vasodilation
        - Local increase H^+ >>>>>> local vasodilation
    - The local vasodilation of all the above cause a local increased blood flow
- Blood flow to the brain
    - Since the metabolic rate to the brain is always constant, blood flow to the brain remains constant.
    - The brain has the ability to maintain constant blood flow between 60 and 150 mmHg (MAP)
    - Cerebral arteries **constrict** when systemic BP rises or when P_aCO_2 decreases or when P_aO_2 increases
    - Cerebral arteries dilate when systemic BP falls or when P_aO2 decreases or when $PaCO_2$ increases
    - Effect of hyperventilation on cerebral vessels

Hyperventilation >>>> Decreased CO_2 >>>> Cerebral Vasoconstriction >>>> Decreased Cerebral Blood Flow

- The effects of chemical mediators of inflammation on local blood flow

Injured Tissue Cells Release Chemical Mediators of Inflammation >>>>>> Local Vasodilation (erythema) and Increased Increased Capillary Permeability

Cardiovascular Regulation



Cardiovascular Homeostasis: Adjustments to Physiological Stress

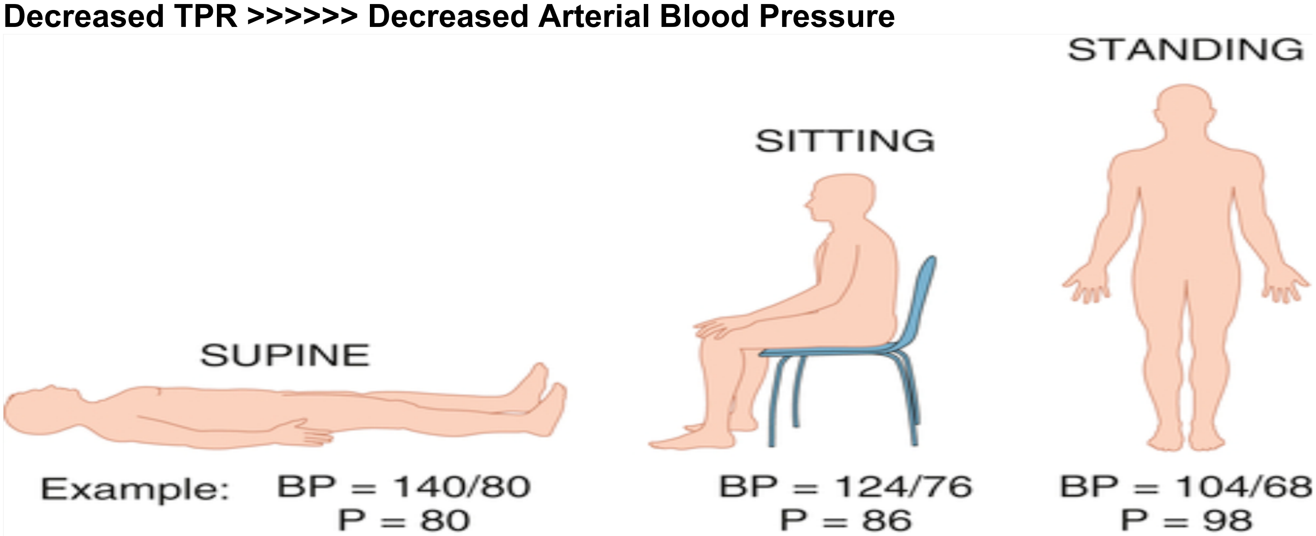
- The Effect of Gravity
    - The effect of gravity in the reclining position
        - Gravity's effect is minimal, since all the vessels are at the same vertical level of the heart
        - The blood pressure in the vessels is due solely to pumping action of the heart
        - BP of head = BP of feet
    - The effect of gravity in standing position
        - Gravity pulls blood toward the ground producing a "hydrostatic pressure" in the feet = 80 mm Hg
        - Gravity acts to increase blood pressure below the level of the heart, while lowering blood pressure above the level of the heart
            - This effect results in 2 major problems:
                - Increased filtration of fluid <u>out</u> of the capillaries (especially in the feet) causing edema
                - Decreased venous return of blood back to the heart

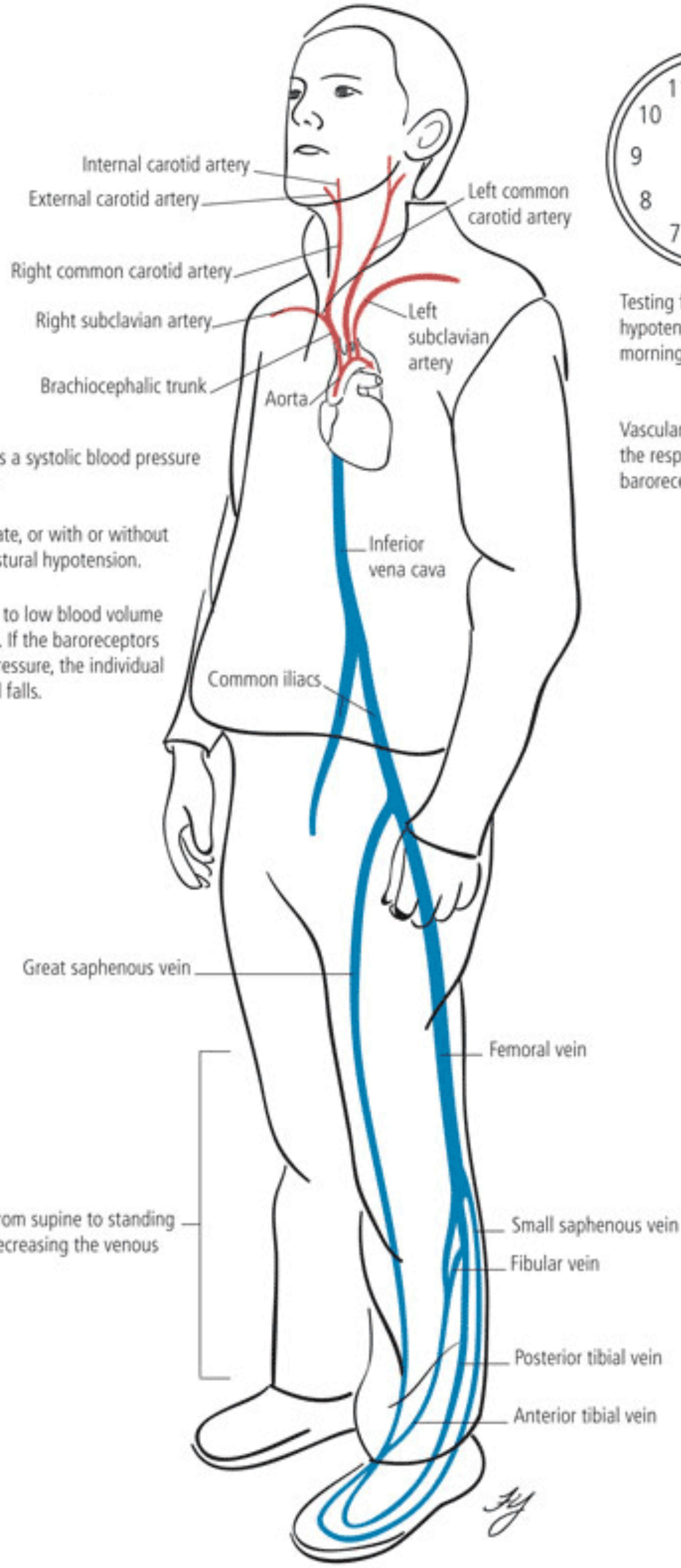
Parameter	Reclining	Sitting	Standing
Heart Rate	**66**	**72**	**83**
Blood Pressure	**112/70**	**120/72**	**125/82**

- The Effect of Body Temperature in Postural Hypertension

Thermoregulation

Increased Body Temp >>>>>>>>>>>>>>> Reflex Cutaneous Vasodilation >>>>>>> Decreased TPR >>>>>> Decreased Arterial Blood Pressure





Within 3 minutes of standing, if there is a systolic blood pressure drop ≥ 20 mm Hg, or a diastolic blood pressure drop ≥ 10 mm Hg, with or without an increase in heart or pulse rate, or with or without symptoms, the individual may have postural hypotension.

The prevalence of baroreflex sensitivity to low blood volume and cardiac output decreases with age. If the baroreceptors are not triggered to normalize blood pressure, the individual may experience dizziness, syncope, and falls.

When an individual changes position from supine to standing blood pools in the lower extremities, decreasing the venous blood volume returning to the heart.

Testing for signs of postural hypotension is best seen in the morning before breakfast.

Vascular stiffness with age can limit the responsiveness of the baroreceptors.

The Effects of Exercise on Cardiovascular Homeostasis

- Exercise is another example of physiological stress mediated by sympathetic reflexes
- The Cardiovascular System increases blood flow (and thus, O_2 delivery) to the active tissues primarily in two ways:
    - Increased Cardiac Output
        - Increased rate of flow through the body
        - Increased myocardial contractility
        - Increased vasoconstriction
    - Diversions of blood to only the vital organs and active tissues of the body
        - Arteriolar vasoconstriction to the inactive regions >>>>> decreased blood flow
        - Arteriolar vasodilation to the active regions >>>>>> increased blood flow
    - Long term effects of regular exercise on the cardiovascular system
        - Hypertrophy of heart
        - Increased collateral circulation
        - Bradycardia
        - Decreased arterial blood pressure

Pathophysiological Considerations

- **Circulatory Shock – Acute Hypotension**
    - Types of Shock
        - Cardiogenic Shock
            - MI, CHF, Cardiac arrhythmia
        - Hypovolemic Shock
            - Hemorrhagic shock – loss of blood
            - Shock due to extensive burns or trauma
                - Loss of plasma proteins and fluid
            - Shock associated with dehydration
                - Via kidneys (diabetes)
                - Via GI tract (vomiting, diarrhea)
        - Anaphylactic Shock

Acute hypersensitivity reaction >>>>>>
Release of Chemical Mediators of Inflammation >>>>>>
Generalized Vasodilation >>>>>> Decreased TPR >>>>>> Decreased Arterial BP

Pathophysiological Considerations

- **Cardiovascular Adjustments to Shock**
    - Shock is a physiological stress that produces reflex responses primarily mediated by the sympathetic division of the ANS
    - Consider Hemorrhagic Shock
        - Baroreceptor Reflex
            - Increased cardiac output
                - Increased heart rate
                - Increased myocardial contractility
                - Venoconstriction >>>>> increased venous return
            - Generalized arteriolar vasoconstriction
                - Increased TPR
                - Diversion of blood to only the vital organs of the body

Cardiovascular Effects & Responses Following 20% Loss of Blood Volume

Parameter	Before Hemorrhage	Immediately After Hemorrhage	5 minutes After Hemorrhage
Heart Rate	**70 BPM**	**70 BPM**	**91 BPM**
Stroke Volume	**75 ml / beat**	**40 ml / beat**	**53 ml / beat**
Cardiac Output	**5250 ml / min**	**2800 ml / min**	**4775 ml / min**
Kidney Blood Flow	**1300 ml / min**	**1000 ml / min**	**850 ml / min**
Brain Blood Flow	**750 ml / min**	**500 ml / min**	**700 ml / min**