The Cardiac Cycle:

1. The cardiac cycle is from the end of one heart contraction to the end of the next.
2. It is initiated by the spontaneous generation of an action potential in the SA node.
3. Contraction begins a few milliseconds after the action potential and continues to contract a few milliseconds after the action potential ends.
4. There is a period of relaxation (Diastole) followed by a period of contraction (systole).

Function of Ventricles as Pumps: The Filling of the Heart

1. During ventricular systole, ***the atrium fills with blood*** because the atrioventricular valves are closed (tricuspid and bicuspid).
2. When the left ventricular pressure exceeds the aortic pressure, ***the aortic and pulmonary valves open and*** blood is pumped into the aorta or pulmonary artery (during systole).
    a. ***The ventricles contract isovolumetrically*** (there is no change in volume → only a change in the pressure of the ventricles). This contraction causes the pressure in the ventricles to rise.
    b. The aortic valve opens with the pressure in the ventricles reach about 80mmHg, and blood flows from the ventricles into the aorta.
3. When the rate of ejection out of the ventricles begins to fall as the blood is expelled, the ventricular pressure drops below the atrial pressure and ***the mitral valve opens*** →this allows blood that accumulated during systole in the atrium) to flow rapidly into the ventricles → ventricular filling occurs during diastole, and atrial filling occurs during systole.
    a. The filling of the ventricles is *PASSIVE*, the contraction of the atria is just "squeezing the sponge"…→ the AV valves are open during diastole…and closed during systole.
    b. The decline in pressure also forces the ***semi lunar (aortic/pulmonary) valves closed.***
4. ***Under Normal Conditions…***Atrial Systole IS NOT essential for ventricular filling → it just "tops off" the ventricles.
    a. During ***Atrial Fibrillation*** – there is no coordinated contraction of the atria…a person may have this under normal conditions and; not know because the ventricles fill passively.
        i. Downside is you don't get normal blood flow → this causes a stasis of blood: The blood pools with in the atria; ***blood stasis*** increases the chance of developing blood clot formation.
        ii. People with chronic atria fibrillation often require anticoagulants.
    b. ***But During periods where increased Cardiac Output is necessary, the*** absence of atrial systole can limit the ventricular filling and be a problem.

End-Diastolic Volume, End systolic Volume, and Stroke Volume:

1. The filling of the ventricles increases to about 120-130mL during Diastole → this is called the ***END DIASTOLIC VOLUME.***
2. ***THE STROKE VOLUME*** is the amount of blood that is pumped out of the ventricles during systole → this is about 70mL (about 60% of the end diastolic volume is expelled).
3. ***End Systolic Volume*** is the remaining volume in each ventricle at the end of systole (~50-60mL)
4. The fraction of the end-diastolic volume that is ejected ***(ejection fraction***) is about 60% (70/120).
    a. This is the fraction of the blood that is expelled from each ventricle during each contraction.
    b. Patients with heart failure have an ejection factor of < 40%; there are varying degrees of this.

Heart Sounds:

1. Normally two heart sounds are heard; there may be a 3rd or 4th under abnormal circumstances.
2. Heart sounds are associated with the closing of the valves.
3. ***S_1 (the first heart sound)*** signals the beginning of systole.
    a. This occurs as the ventricles contract and the ventricular pressure rises above the atrial pressure → this causes the ***atrioventricular valves*** to close.
    b. It is hear as a low pitched "lub" caused by the vibration of the valves and walls of the heart.
4. ***S_2 (the second heart sound)*** - Occurs at the end of systole when the aortic and the pulmonary (semi lunar) valves close.
    a. This is heard as a high pitched "dub" that may have two components: the closing of the aortic valve and the closure of the pulmonary valve.
    b. The splitting of the sound may be heard with inspiration and sometimes this sound disappears with exhalation.
5. ***S_3 (the third heart sound)***- This is due to passive rapid filling of the ventricles and can signify the presence of a cardiac abnormality → such as CHF (which is associated with rapid filling and overfilling.

Cardiac Output (CO):

1. ***The Stroke Volume (SV)*** is the amount of blood ejected from the left ventricle during contraction.

SV = CO/HR
CO = HR * SV
CO = Cardiac Output
SV = Stroke Volume
HR = Heart Rate

   a. The ***Cardiac Output*** is the volume of blood ejected from the heart per unit of time.
   b. The cardiac output depends on the tissue demands; the heart can increase the cardiac output by about 7 times → there is a way to standardize CO (because not everyone is the same because people are different sizes)
      i. Look at the ***Cardiac Index = CO / Body Surface Area***
         1. All normal healthy people should have about the same cardiac index.
      ii. Normally, the CO is 4-7mL/mion; and a normal heart rate is 60-100 BPM.
      iii. Normally, the continual increase of heart rate will not continue to increase the cardiac output → but there is a plateau (about HR 170-180 BPM). ***Above that critical level, the cardiac output will actually decrease.***
         1. ***CO will decrease*** because there will be an over utilization of energy substrates.
         2. Will decrease because the will be a ***decrease in the filling time****;* there is not enough time spent in diastole to fill the ventricles.
      iv. The Volume of blood pumped is regulated by two main Factors:
         1. ***Venous Return*** – the response to changes in blood flowing into the heart.
            a. There is a regulation of blood pressure by peripheral tissues.
               i. The heart essentially pumps out whatever is returned to it.
               ii. The heart can adapt inputs from 2 – 25L → this ability of the heart to adapt to varies blood flows is know as ***the frank stirling law***.
         2. ***The reflex control*** of the heart by the autonomic nervous system.
            a. *The Parasympathetic releases* Ach, which decreases heart rate.

b. *The sympathetic nervous* system releases epinephrine and Norepinephrine → increases heart rate.

Factors That Influence Cardiac Output:

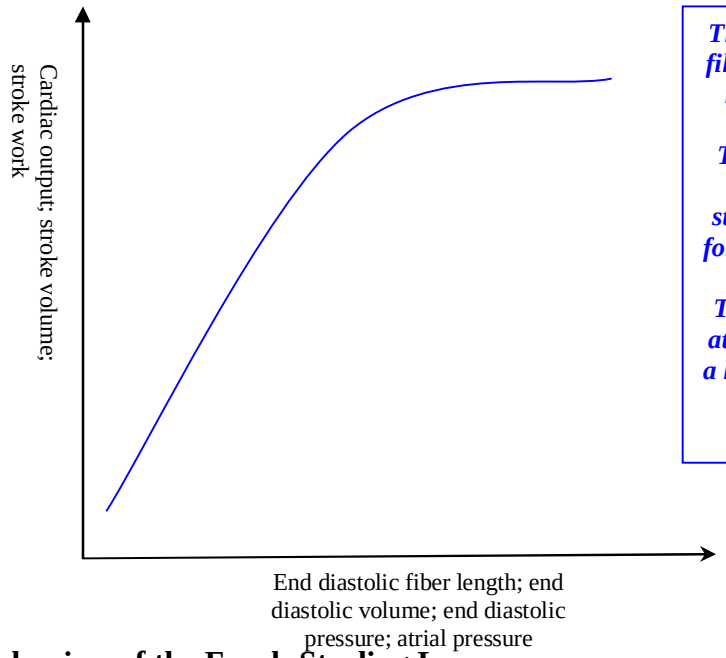
1. Stroke Volume
    a. The Force of Contraction is affected by several factors:
        i. End-diastolic fiber stretch (AKA – ***Preload***)
            1. This deals with the ***Frank Sterling Law*** → the more the fibers are stretched, the greater the preload, so the greater the force.
        ii. The ***Contractility*** can also be affected → an increase in contractility will result in an increase in force.
            1. Sympathetic stimulation increases contractility via β – Receptors.
            2. Drugs can affect the contraction force: Digoxin increases the contraction force, anesthetics and toxins decrease contractility.
            3. Diseases, such as coronary artery disease, and myocarditus may have a (-) affect on contraction and decrease the contractility.
    b. ***Excessive after load*** also has a negative effect.

Problem with Heart Failure Patients: their α_1 receptors, when the are stimulated, causes a vasoconstriction by the sympathetic nervous system in an attempt to increase the cardiac output: This is bad because if the partied has a weakened heart and has to pump against a higher pressure: results in progressive weakening of the heart.

2. **Heart Rate**
    a. The Heart Rate can be altered by the Autonomic Nervous system.
    b. It is also under reflex control → a stretch in the atria (right) will reflexively increase the heart rate from 10 – 30% (this mechanism relates to the hearts ability to adapt). ; But the contribution of this is much less than the Frank Starling mechanism.

The Frank Starling Law:

1. ***As the stretch of the heart increases***, the volume of the blood that is ejected with each systolic contraction (stroke volume) also increases.



The diagram says: As the filling of the left ventricles is increase, the cardiac output will increase. The more blood there is, the more the heart will stretch, so the greater the force; so the CO increases.

The line begins to flatten at a certain level: there is a limit → beyond that limit the CO will not be increased any more.

The Mechanism of the Frank-Starling Law:

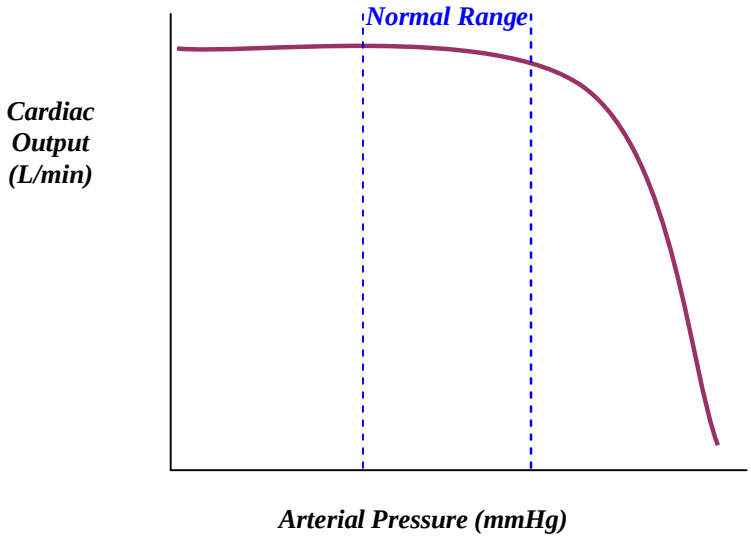
1. When Cardiac muscle is stretched an extra amount, as it does when extra amounts of blood enters the heart chambers, the stretched muscle contracts with a greatly increased force, thereby pumping extra blood into the arteries ***(ex. Increase stretch → increase contractility).***
2. The volume of blood in ventricles at the end of diastole (preload) is sometimes expressed as pressure (***LVEDP*** → this denotes the stretch of the left ventricle: end diastolic volume).
3. In some abnormal states of the heart or circulation, preload and/or after load are severely altered from normal.
    a. For example; Patients with hypertension or heart failure.
    b. ***In patients with heart failure (weakened heart):*** the CO decreases, and various mechanisms are activated with in the body that try to increase the heart rate:
        i. Tries to increase the HR and SV…SV increase returns more volume to the left ventricle.
        ii. Patients end up with stasis because the blood backs up into pulmonary circulation and the patients get pulmonary edema → symptoms include SOB.
4. **The Effects of Contractility:**
    a. Increased contractility → more blood ejected

b. Increases with increased activity of the sympathetic nervous system
c. Contractility can be altered by drugs, and disease.

The Effects of Hypertrophy:

1. Hypertrophy is the increase in muscle mass; may occur within the left ventricle; this leads to more work or more stretch.
2. Results in increase force of contraction
3. This is a long term adaptation of the heart to stress (the building of more muscle mass).
4. The ventricular cells enlarge, the walls thicken, and it is capable of greater force development.
5. Repeated bouts of increased cardiac output results in increased synthesis of contractile proteins and enlargement of cardiac muscle cells.
    a. This results in decrease ventricular volume because the space is occupied by tissue, so it has a negative affect on cardiac output.
    b. This is seen in people with heart failure or people with long standing hypertension…In the short tem it is good because it leads to an increase in cardiac output.

The Affects of Afterload:



The Diagram illustrates normal operating range (ranges from 80 to 170 mmHg. There is an increase in arterial pressure, and increase in after lead, but there is no effect on CO (this remains constant) After lead > no mmHg leads to a decrease in CO

The Measurement of Cardiac Output:

1. ***Fick Principle:***
    - ***a.*** The Dye dilution method – dye is injected (a known concentration), and its concentration is measure vs. time; the concentration is followed with a detector.
    - ***b.*** This method requires extrapolation.
2. ***The Oxygen Consumption Method:***
    - ***a.*** CO = Oxygen consumption/Arterial Blood Oxygen content.
3. ***Themodilution Method –*** This is the method used in most clinical situations.
    - ***a.*** The Swan-Ganz Catheter – This is how it is usually measured; has 4 or 5 arms with pores
    - ***b.*** The catheter is inserted into the subclavian vein; able to follow via the monitor screen → it takes the blood flow into the right atrium to the Left ventricle to the pulmonary artery.
    - ***c.*** The balloon is slightly inflated at the end.
    - ***d.*** This gives CO information; known volume of solution is injected and is measure vs. time
    - ***e.*** The balloon at the end is inflated in the pulmonary artery; it wedges in the artery.
        - ***i.*** There are pressure sensors at the end; when the mitral valve opens; the balloon measures the preload → so get the pressure in the whole left side of the heart; able to get info about the volumes from the pressure; deviations from the norm give you estimations of volume.

Circulation and Hemodynamics

1. ***Hemodynamics –***Describes the relationships governing the physical principles of pressure, flow, resistance, and compliance as the relate to the cardiovascular system.
2. ***Poiseuille's Law:***
    - ***a.*** Fluid Flows when a pressure gradient exists
    - ***b.*** The volume of fluid flowing through a rigid tube per unit time ***(flow)*** is proportional to the pressure difference ***(gradient)*** between the ends of the tube.
        - ***i.*** The tubes are not elastic → they are rigid.

$$\textbf{Blood Flow} = \frac{\Delta P \pi r^4}{8nL}$$

r = radius of tube
n = viscosity of flow
L = length of the tube
ΔP = Pressure difference.

c. The most important determinants of blood flow are P and r → this is because these are the only variables that are capable off change.
- ***i.*** The radius is the most important variable → the body has mechanisms to try and maintain a constant force, so the Blood pressure is mostly controlled by changing the radius of the blood vessels.

d. ***Resistance to Flow:***
- ***i.*** $R = P/Flow = 8nL/\pi r^4$
- ***ii.*** The resistance is not measure by any direct means (it is calculated form the P and Flow)
- ***iii.*** The resistance depends largely on the diameter of blood vessels.

e. ***The Effect of Viscosity (Hematocrit):***
- ***i.*** The Hematocrit is the % of the blood that is cells
- ***ii.*** This number is obtained by centrifugation.
- ***iii.*** The greater the Hematocrit, the greater the friction
- ***iv.*** The contribution is minimal because normally don't see changes in the viscosity.

Streamlined or Turbulent Flow:

1. ***Streamlined Flow***
   a. The fluid exerts least resuistance to flow
   b. Concentric layers of fluid slip past each other.
2. ***Turbulent Flow***
   a. Crosscurrents.

Factors Contributing to Turbulence:

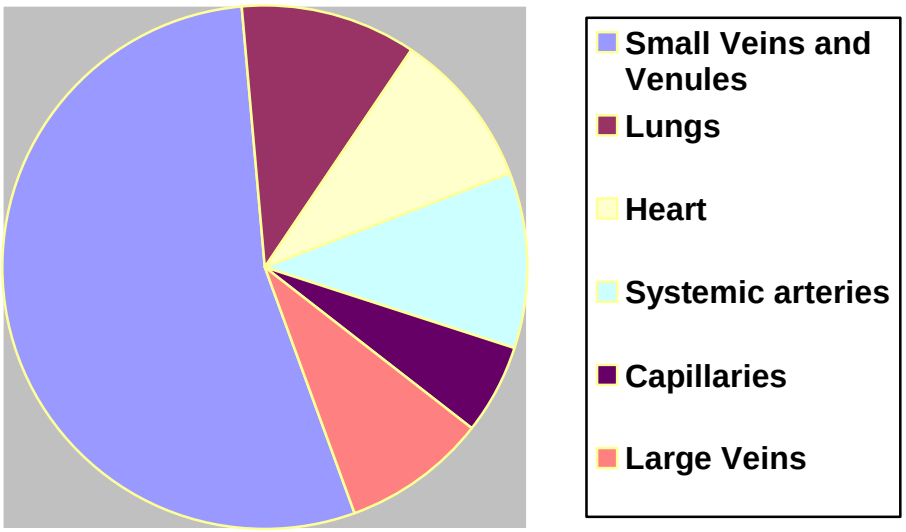
1. High Flow Velocity
2. Large tube diameter
3. High fluid density
4. Low viscosity.

Reynold's Number
$N_R = vd\rho/\eta$
V = velocity
d = the diameter of the tube
ρ = the fluid density
η = viscosity

5. If the $N_R > 3000$; then the flow will be turbulent (this is only normally exceeded in the aorta just beyond the aortic valve → the aorta has a large diameter and a large flow velocity.
6. $N_R < 3000$; there is a stream line flow.
7. N_R between 2000 and 3000; may have various flow patterns.
8. *Two examples when turbulent flow may occur:*
   a. Stenotic Valves (narrowing of the valves) → this generates vibrations because of turbulence***: Heart murmurs.***

b. ***Bruits*** – If turbulence occurs in blood vessels, the same thing at different locations → just different names.

Quantities of Blood in different Parts of the Circulation.



~20%of the blood is NOT in systemic circulation
Most of the blood in the systemic circulation is contained in the veins: low Pressure, elastic (expands around the blood. → 80% of the total blood volume is located in systemic circulation

Cross Sectional Areas and Velocity of Blood Flow:

There is a larger cross sectional area of veins in compared to arteries; The Velocity of Blood flow is proportional to cross-sectional area.

SO AORTA HAS THE LARGEST VELOCITY→ SMALL CROSS SECTIONAL AREA CAPPILARIES HAVE A LARGE CROSS SECTIONAL AREA AND A SLOW VELOCITY.

Total Cross Sectional Area	Cm^2
Aorta	2.5
Small Arteries	20
Arterioles	40
Capillaries	2500
Venules	250
Small Veins	80
Vena Cava	8

The capillaries have the larges cross sectional area

1. There is a decrease in arterial pressure in each segment of the systemic circulation → the pressure is directly proportional to the vascular resistance in each segment; so small diameter vessels should have greatest P proportionally;. talking about a decrease in pressure
2. Small B.V radius means larger resistance → inverse relationship.
3. The pressure progressively falls (in the Right atrium the P = 0mmHg
4. Decrease in arterial pressure in each segment is directly proportional to the vascular resistance in the segment.
5. SVR is frictional resistance to blood flow
6. Small arteries, arterioles, and capillaries account for 90% of vascular resistance.