Distensibility and compliance:

- Distensibility is the proportional increase in volume per 1 mmHg increase in pressure. So it is a ratio. So if you want to describe it, you describe it as - for example - 10% not 10.
- Compliance is how much volume needed in order to increase the pressure by 1 mmHg.
- Distensibility equation: \(D = \frac{\Delta V}{\Delta P \times V} \times 100\%\)
- Compliance equation: \(C = \frac{\Delta V}{\Delta P}\) (here it is not multiplied by 100% because it is not a ratio)
- Compliance can also be calculated using dispensability. \(D = \frac{\Delta V}{\Delta P \times V}\). By rearranging the equation: \(\frac{\Delta V}{\Delta P} = D \times V\). And because \(C = \frac{\Delta V}{\Delta P}\), then compliance equals \(D \times V\). So compliance is dispensability multiplied by the volume.
- \(\Delta V\) is the added volume.
- \(V\) is the original volume
- \(\Delta P\) is the change in pressure

Examples:
- If we have 100 ml volume (the original volume), if we add 10 ml, the pressure increases 1 mm Hg \((10 / (1 \times 100) \times 100\% = 10\%\) which refers to the distensibility while the compliance here is 10 ml), if the volume was 120 so the compliance = 12 ml and so on.
- If the original volume was 90 and we needed to add 10 ml to increase pressure by 1 mmHg then Distensibility equals \(10 / (90 \times 1) \times 100\%\). So the distensibility changed. The compliance will not change in this case and it will stay 10 ml because \(\Delta V\) was not changed.
- If the original volume was 90 ml and the distensibility = 10%, how much do we need to achieve rise of 1 mm Hg? 9 ml (which represents the compliance).

Pulsation waves

- If we count the heart rate, each beat represents one cardiac cycle thus one pulse.
- These pulses are waves that move in the wall of the artery (so what we feel during the heart rate counting is not due to the flow but because of the movement of the
wall which is a very fast movement that depends on the compliance of the vessel thus if the compliance is high, the velocity is low and if the compliance is low, the velocity is high). {pulsation wave velocity definition (from the internet and not mentioned by the doctor): it is the velocity at which the blood pressure pulse propagates through the circulatory system} 

- The pulsation we feel in arteries is caused by the pulsation wave not by blood flow

❖ Velocities of pulsation waves in different vessels:
- The artery with the highest compliance among all arteries is the aorta so it has the slowest pulsation (4-5 m/s). (But not slower than veins)
- The speed of pulsation in large arteries (10-20 m/s) is higher than the aorta because their compliance is less. The speed of pulsation in small arteries is higher than the aorta and large arteries because their compliance is lower than the aorta and large arteries.
- Arterioles have the fastest pulsation speed which may reach 40 m/s as they have the lowest compliance {remember that arterioles have the highest resistance because they have the lowest compliance}
- Veins have higher compliance than all arteries so they have lower pulsation speed than arteries
- So in the order of compliance: Veins>Aorta>Large arteries>Small arteries>Arterioles
- In the order of pulsation speed: Arterioles>Small arteries>Large arteries>Aorta>Veins

❖ Pulse pressure

- As we know, there are two pressures in the single pulse which are systolic and diastolic. The difference between the systolic and the diastolic is called the pulse pressure. (Systolic pressure – Diastolic pressure)
Pulse pressure is the cause of the pulsation wave in blood vessels

Example: if the measured pressure is 110/70, then how much is the pulse pressure? It is the difference between systolic and diastolic, so it is 110-70 which equals 40.

- Factors affecting the pulse pressure:
  1. Stroke volume: the higher the stroke volume, the higher the pulse pressure.
     - Why? When stroke volume is increased, the blood pressure inside the aorta increases (because there is more blood inside the aorta). This means an increase in the systolic pressure. Increasing the systolic pressure will increase the difference between it and the diastolic pressure. This will increase the pulse pressure.

  2. Compliance: high compliance means that if you increase the blood volume in the vessel, the vessel wall will expand with the blood so there will be no big change in the pressure. But if the vessel has low compliance, the wall will not expand with the increased blood volume. So a small increase in the blood volume will increase the pressure a lot.
     - A high compliant vessel will have lower pulse pressure than a low compliant vessel.

As you can see, the pulse pressure also depends on the ratio between the stroke volume and compliance. If you increase the stroke volume without increasing the compliance, the pulse pressure will increase. If you increase the compliance without changing the stroke volume, the pulse pressure will decrease.

You can change stroke volume and compliance without affecting the pulse pressure if you increase or decrease both of them proportionally. Example: if they were 2/4 and increased both of them to 3/6 the ratio between them will not change, so there will be no change in the pulse pressure.
Stroke volume will increase in:

1- Aortic regurgitation: aortic regurgitation means the return of blood from the aorta back to the left ventricle. So, if the stroke volume before the regurgitation was 70ml and the aorta returned 30ml back to the left ventricle; the stroke volume in the next cycle will be 70+30 which equals 100ml. With the stroke volume increased, the systolic pressure is increased and therefore the pulse pressure is increased.

   - Aortic regurgitation is also associated with low diastolic pressure. When the blood goes back from the aorta to the left ventricle, the aorta will have less blood during diastole so the diastolic pressure will decrease. Less diastolic pressure means higher pulse pressure.
   - Also in aortic regurgitation there will be no incisura. Incisura is caused by the turbulence of blood around the semilunar valve. So in this case, the valve will be open and there will be no turbulence of blood thus no incisura.

2- Patent ductus arteriosus: normally in the embryo, there is an artery between the pulmonary artery and the aorta called the ductus arteriosus. It connects them together so blood can go directly from the pulmonary artery to the aorta. This is because the embryo is not using his lungs so he doesn’t need blood going to the lungs. After birth, this artery will close. If it stays open, then this condition is called patent ductus arteriosus. In this condition, blood from the right ventricle will skip the pulmonary circulation and go to the left ventricle. This will increase the stroke volume and so the pulse pressure will increase.

   - Compliance is decreased in atherosclerosis as the vessel becomes more rigid.

**So in conclusion, stroke volume is directly proportional to pulse pressure and compliance is inversely proportional to pulse pressure.**
*A little talk about the mean arterial pressure:
- It equals $\frac{2}{3}$ diastolic + $\frac{1}{3}$ systolic
- It equals 40% of the diastolic + 60% of the systolic
- It also equals $CO \times TPR$
- It is affected by the cardiac output and the total peripheral resistance
- It also equals diastolic pressure + 1/3 pulse pressure (the doctor explained the derivation of this formula but I didn’t understand it. You can find it at 13:40 in the video)

**Blood pressure regulation:**
- Blood pressure is one of the most important variables that have to always be almost constant because it drives the flow of blood to different tissues
- If a patient has a very low blood pressure, he will develop shock.

  - Short and long term regulators:
    - As we know, there are two control systems in the body: neurons and chemicals (hormones)
    - Neurons are very fast because they use action potential.
    - Chemicals are slower than neurons because they may need a certain concentration to produce an effect and because they are transported by blood.
    - So the short term regulators are the neurons.
    - Chemicals can be intermediate term regulators and long term regulators. They may take from 1 hour to several hours and several days to produce an effect; so in this case they are intermediate term regulators. Long term regulators may take weeks and even months to cause their effect.

  - How do Short term regulators work: they usually reset the blood pressure back to the normal pressure for the person. Example: if a person has a normal mean arterial pressure of 100mmhg and his blood pressure elevated to 120mmhg, the short term regulators will work to reset it back to 100mmhg. But their problem is that they will not return it exactly back to 100, there will be some error. So if they return it to 105mmhg, they have corrected the pressure by 15mmhg and made an error equal to 5mmhg. So the correction-error ratio is 3. If they returned it to 100.01, the correction-error ratio will be \( \infty \) as the error is almost 0.

  - If a person has a normal blood pressure of 100 and they had elevated blood pressure of 120 for a week for example, the short term regulators will set 120 as the new normal blood pressure. That is why they are not important for
regulating blood pressure for long terms. This case needs long term regulators. {short terms that neurons regulate are like you laying down and suddenly standing up, the pressure will decrease suddenly; so they will work to return it back to normal quickly.}

**How to measure blood pressure:**
- We use an instrument called ‘Sphygmomanometer’ or it is also called the mercury manometer.
1- You put the cuff around the arm and put the stethoscope on the antecubital artery (not the vein because they have a very weak pulsation) and listen to it

2- You raise the pressure of the manometer above the systolic. This way, there will be no blood flow and you will not hear any sound.

3- Keep decreasing the pressure until hearing the first sound (a tapping sound). This indicates that there is blood flow during systole because the manometer pressure now is equal to or less than the systolic pressure. The sound heard is caused by the turbulent flow of blood. The turbulent flow is caused by arterial constriction which is caused by the manometer cuff. {There will be no sound during diastole because the manometer pressure is still higher than the diastolic pressure so there will be no blood flow}

4- Keep decreasing the pressure until the sound disappears. The sound disappears because the flow became laminar. It became laminar because the cuff has low pressure so it is not constricting the artery anymore. The pressure at which the sound disappears is equal to the diastolic pressure.
   -So the beginning of sound marks the systolic pressure and the disappearance of the sound marks the diastolic pressure.

- This method of measuring the blood pressure is called the Auscultatory method

   **Example:** If the pressure of the person is 120/80; when the manometer pressure becomes above 120 the blood flow stops and there will be no sound. When it becomes lower or equal to 120, blood will start to flow and a sound can be heard. This sound is caused by the turbulent flow. So, the pressure that you hear the first sound at is the systolic pressure (120 in this case). Keep decreasing until it reaches 80, the sound will disappear and the flow will become laminar
because the cuff is not constricting the artery anymore. So, the pressure that the sound disappears at is the diastolic pressure (80 in this case).

As you can see, there is a sound at 120, then the sound disappears and it comes back again. This disappearance happens during diastole because the pressure of the manometer is higher than the diastolic pressure so there will be no blood flow during diastole. No sound will be heard at a pressure lower than 80.

**Mean arterial pressure:**

- The mean arterial pressure is closer in value to the diastolic pressure than the systolic because it equal \(2/3 \text{diastolic} + 1/3 \text{systolic}\)

Mean arterial pressure can also be calculated by calculating the area under the curve by using integration from \(t_2\) to \(t_1\)

- \(\text{MAP} = \text{Cardiac output} \times \text{total peripheral resistance}\). So if you want to
change the arterial pressure you change one of them or both of them.
-You can change the cardiac output by changing the stroke volume or the heart rate or both

**Blood vessels and the autonomic nervous system:**

- Blood vessels are only supplied by the sympathetic. They are not supplied by the parasympathetic. The parasympathetic only supplies the heart.
- All vessels are supplied by the sympathetic except capillaries. Capillaries are not supplied because they lack smooth muscles.

- Vessels have a tone. This means that there is some contraction under basal conditions. This contraction allows the vessels to dilate and constrict more. If there was no tone, they would not be able to constrict.

**Short term regulation of blood pressure:**

- Short term regulators are nervous regulators and they are called baroreceptors.
- In order for these nerves to regulate the blood pressure, they need to sense the change that happens in the blood pressure. How? There are specialized receptors that sense the change in pressure.
- These receptors are located near the heart. They are near the heart so that they immediately sense the change in pressure and react quickly.
- Their locations are: 1-the wall of the aortic arch 2-the carotid sinus at where the common carotid bifurcates into the internal and external. They are at the beginning of the internal carotid artery.
- These receptors are stretch receptors. They are found in the wall of the artery. So if the wall of the artery becomes more stretched or less stretched, they sense this and respond immediately.

**Nervous supply of the baroreceptors:**
- Receptors in the *carotid sinus* are supplied by the *glossopharyngeal nerve* (the 9th cranial nerve). The branch from the glossopharyngeal that supplies these receptors is called Hering nerve.
- The glossopharyngeal nerve sends impulses from these receptors to the cardiovascular center in the medulla oblongata in the brain.
- Receptors in the *aortic arch* are supplied by the *vagus nerve* (the 10th cranial
nerve.
- The vagus nerve also sends impulses from these receptors to the cardiovascular center in the medulla oblongata in the brain.

**The cardiovascular center in the medulla oblongata:**
This center is divided into: cardiac center and vascular center.
- The cardiac center has two centers:
  1. The cardioacceleratory center which increases the heart rate. It increases the heart rate by sending impulses to the heart through the sympathetic nervous system.
  2. The cardio inhibitory center which decreases the heart rate. It decreases the heart rate by sending impulses to the heart through the vagus nerve.

- The vascular center is called the vasomotor center. It has three areas:
  1. Sensory area: it receives the sensation
  2. Vasoconstrictor area: it sends its impulses to the vessels through the sympathetic
  3. Vasodilator area: it doesn’t send impulses to the vessels. It works by inhibiting the vasoconstrictor area if it is stimulated and if it is inhibited it relieves the inhibition on the vasoconstrictor area.

**What happens when the pressure increase or decrease:**

**When the pressure decreases:** there will be less stretch on the baroreceptors. If there is less stretch, their impulse rate decreases. When the impulse rate decreases, they will send less impulse to the cardiovascular center and less impulses to the vasomotor center.

- Less impulses to the cardiac center will:
  1. Stimulate the cardioacceleratory center. This causes the center to send impulses through the sympathetic to the heart in order to increase the heart rate and increase the contractility and **increase the stroke volume**. This increases the cardiac output causing the arterial pressure to increase back to the normal value.
  2. Inhibit the cardioinhibitory center. This means the inhibition of the vagus nerve which causes the heart rate to increase.
Less impulses to the vasomotor center will relieve the inhibition on the vasoconstrictor area and cause it to release more sympathetic impulses to the vessels. This will constrict the vessels and **increase the total peripheral resistance** which will increase the mean arterial pressure back to the normal value.

**When the pressure increases**: there will be more stretch on the baroreceptors. If there is more stretch, their impulse rate increases. When the impulse rate increase, they will send more impulse to the cardiovascular center and more impulses to the vasomotor center.

More impulses to the cardiac center will:
1- Inhibit the cardioacceleratory center. This causes the center to send less impulses through the sympathetic to the heart in order to decrease the heart rate and decrease the contractility and **decrease the stroke volume**. This decreases the cardiac output causing the arterial pressure to decrease back to the normal value.
2- Stimulate the cardioinhibitory center. This means the stimulation of the vagus nerve which causes the heart rate to decrease.
- More impulses to the vasomotor center will increase the inhibition on the vasoconstrictor area and cause it to release less sympathetic impulses to the vessels. This will dilate the vessels and decrease the total peripheral resistance which will decrease the mean arterial pressure back to the normal value.

**Baroreceptor Reflexes**

Response of the baroreceptors to the arterial pressure:
- Carotid sinus baroreceptors respond to pressures between 60 and 180 mmHg
- Baroreceptors reflex is most sensitive at a pressure of 100mmHg

**Baroreceptors function:**
- They work to regulate pressure that can change in a very short time (1 second for example). An example when pressure can change in a very short time: the person changing his posture; meaning that he was supine and stood up or the person was standing up and lied down.
-If he was lying down and stood up, the blood will go down by the effect of gravity and there will be a sudden decrease in the blood pressure. In this case, baroreceptors will work in the term of milliseconds and raise the pressure back to normal very quickly. So the person will not feel any dizziness because the pressure was raised back very quickly. Old people might feel dizzy when standing up because with age vessels become more rigid (less stretchable); so the baroreceptors will become less sensitive and will work at a lower speed. They can overcome this problem by just standing up slowly to give time for the baroreceptors to work.

-If he was standing up and lied down, the blood pressure will increase suddenly. This increase may cause hemorrhage. But the baroreceptors work very quickly to decrease the pressure back to normal so no hemorrhage will happen.