Vascular hemodynamics-3

Effect of blood pressure on tissue blood flow and resistance

- Expectation:
- An increase in arterial pressure will cause a proportionate increase in

  blood flow through the body’s tissues.

- Reality:
- The effect is **less than expected**.

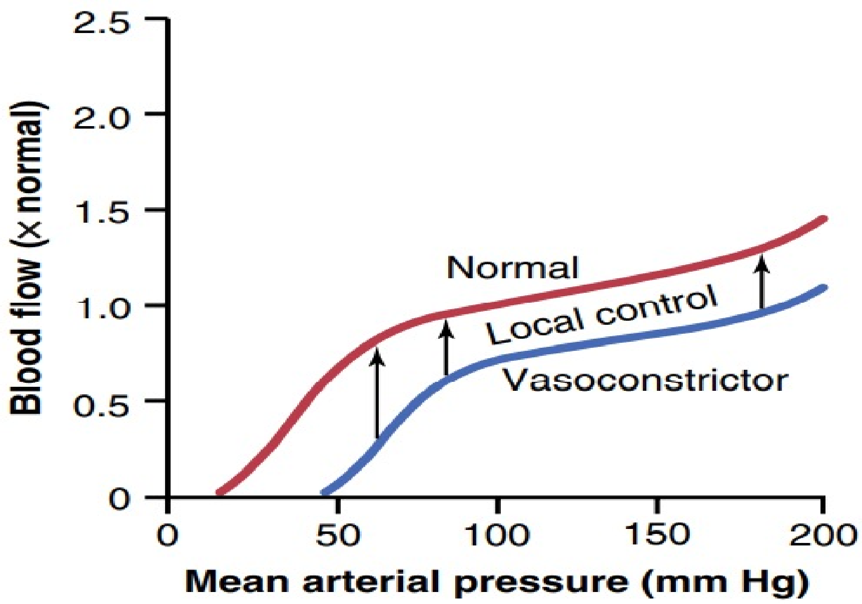
  • Why?

  • Because an increase in arterial pressure not only **increases the force that pushes blood** through the vessels, but also initiates compensatory **increases in vascular resistance** within a few seconds through activation of the local control mechanisms.

  • With reductions in arterial pressure, vascular resistance is promptly reduced in most tissues, and **blood flow is maintained at a relatively constant rate.**

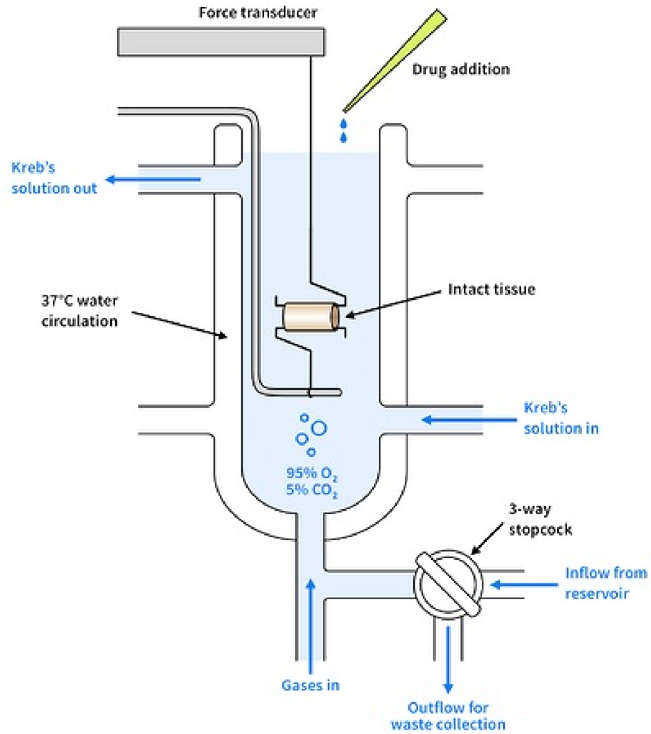
Blood flow autoregulation

• The ability of each tissue to adjust its vascular resistance and to maintain normal blood flow during changes in arterial pressure between approximately 70 and 175 mm Hg.



Reduction in blood flow can be caused by strong **sympathetic stimulation** or hormonal vasoconstrictors which constrict the blood vessels.

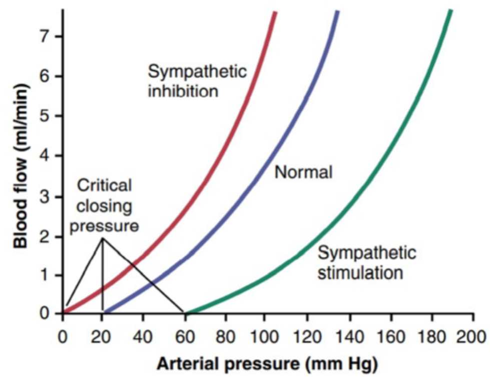
- The effect is usually **transient**, even when increases in arterial pressure or increased levels of vasoconstrictors are sustained.
- The reason for the relative constancy of blood flow is that each <u>tissue's local autoregulatory mechanisms eventually override most of the effects of vasoconstrictors</u> to provide a blood flow that is appropriate for the needs of the tissue.



Pressure-flow relationship in passive vascular beds

- • In isolated blood vessels or in tissues that do not exhibit autoregulation, the **effect of pressure on blood flow can be greater** than that predicted by Poiseuille's equation.
- • The reason for this is that increased arterial pressure not only **increases the force that pushes blood** through the vessels, but also **distends the elastic vessels**, actually **decreasing vascular resistance.**
- • Conversely, **decreased arterial pressure** in passive blood vessels **increases resistance** as the elastic vessels **gradually collapse** due to reduced distending pressure.

- • When pressure falls below a critical level, called the **critical closing pressure**, flow ceases because the blood vessels are completely collapsed.



- Sympathetic stimulation and other vasoconstrictors can alter the passive pressure-flow relationship.
- Inhibition of sympathetic activity greatly dilates the vessels and can increase the blood flow twofold or more.
- Conversely, very strong sympathetic stimulation can constrict the vessels so much that blood flow occasionally decreases to as low as zero for a few seconds, despite high arterial pressure.

Vascular distensibility

- • All blood vessels are distensible.
- • The most distensible of all the vessels are the **veins**. • The fractional increase in volume for each mm Hg rise in pressure.

- $$\text{Vascular distensibility} = \frac{\text{Increase in volume}}{\text{Increase in pressure} \times \text{Original volume}}$$

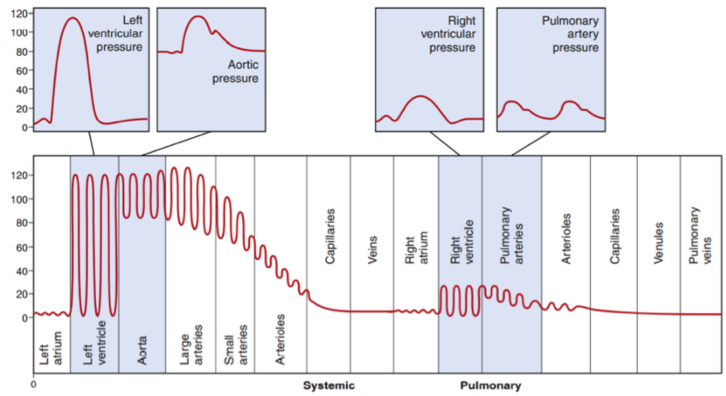
Distensibility

- The walls of the arteries are thicker and far stronger than those of the veins.
- The veins, on average, are about 8 times more distensible than the arteries.
- That is, a given increase in pressure causes about 8 times as much increase in blood in a vein as in an artery of comparable size.

The importance of Distensibility

- Distensibility of the **arteries** allows them to accommodate the pulsatile output of the heart and to average out the pressure pulsations. This capability provides smooth continuous flow of blood through the very small blood vessels of the tissues.
- Even slight increases in venous pressure cause the veins to store 0.5 to 1.0 liter of extra blood. Therefore, the **veins** provide a reservoir for storing large quantities of extra blood that can be called into use

whenever blood is required elsewhere in the circulation.

- 

Vascular compliance (capacitance)

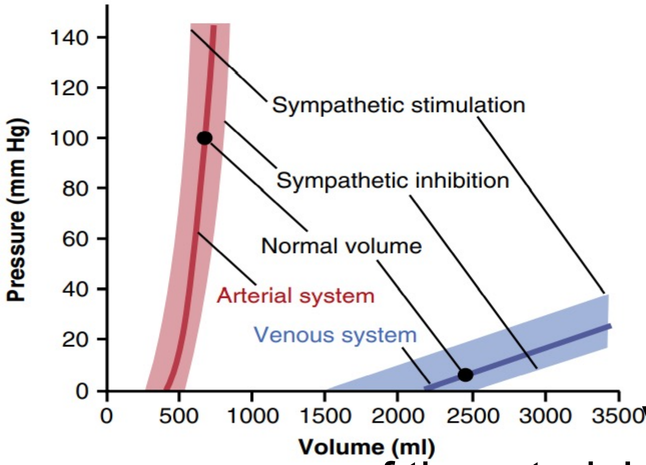
• The total quantity of blood that can be stored in a given portion of the circulation for each mm Hg pressure rise.

• Compliance and distensibility are quite different. •

Compliance = distensibility.volume.

$$\text{Vascular compliance} = \frac{\text{Increase in volume}}{\text{Increase in pressure}}$$

The compliance of a systemic vein is about 24 times that of its corresponding artery because it is about 8 times as distensible and has a volume about 3 times as great (8 × 3 = 24).

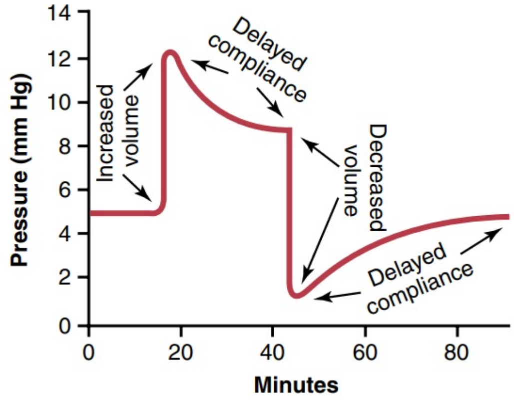


Volume-pressure curves of the arterial and venous circulations

- An increase in vascular smooth muscle tone caused by sympathetic stimulation increases the pressure at each volume of the arteries or veins, whereas sympathetic inhibition decreases the pressure at each volume.
- Control of the vessels by the sympathetics in this manner is a valuable means for diminishing the dimensions of one segment of the circulation, thus transferring blood to other segments.

• Sympathetic control of vascular capacitance is also highly important during hemorrhage.

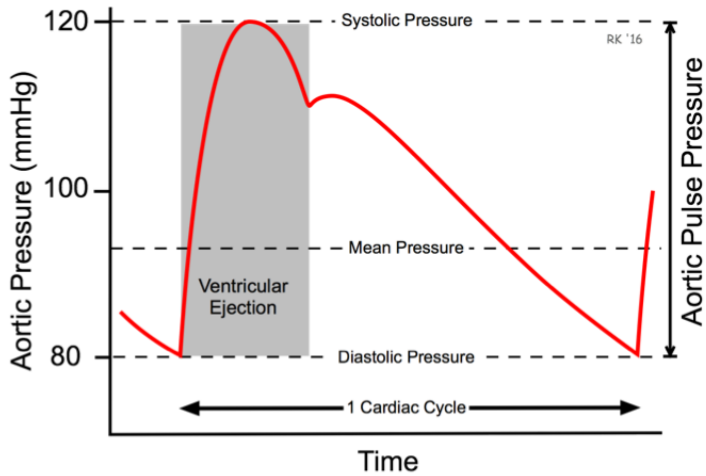
• Enhancement of sympathetic tone, especially to the veins, reduces the vessel sizes enough that the circulation continues to operate almost normally, even when as much as 25% of the total blood volume has been lost.



Delayed compliance of the vessels (stretch relaxation)

- A vessel exposed to increased volume at first exhibits a large increase in pressure, but progressive delayed stretching of smooth muscle in the vessel wall allows the pressure to return toward normal over a period of minutes to hours.
- The added volume of blood causes immediate elastic distention of the vein, but then the smooth muscle fibers of the vein begin to creep to longer lengths, and their tensions correspondingly decrease.
- Delayed compliance is a valuable mechanism whereby the circulation can accommodate extra blood when necessary, such as after a large transfusion.

- Delayed compliance in the reverse direction is one way in which the circulation automatically adjusts itself over a period of minutes or hours to diminished blood volume after serious hemorrhage.



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Mean arterial pressure (MAP)

- The average of the arterial pressures measured millisecond by millisecond over a period of time.
- It is not equal to the average of the systolic and diastolic pressures because at normal heart rates, a greater fraction of the cardiac cycle is spent in diastole than in systole. Thus, the arterial pressure remains closer to diastolic pressure than to systolic pressure during the greater part of the cardiac cycle.
- The mean arterial pressure is therefore determined about 60% by the diastolic pressure and 40% by the systolic pressure.
- MAP (at resting heart rate) = 2/3 DBP + 1/3 SBP = DBP + 1/3 PP.

- • However, at very high heart rates, diastole comprises a smaller fraction of the cardiac cycle, and the mean arterial pressure is more closely approximated as the average of systolic and diastolic pressures.
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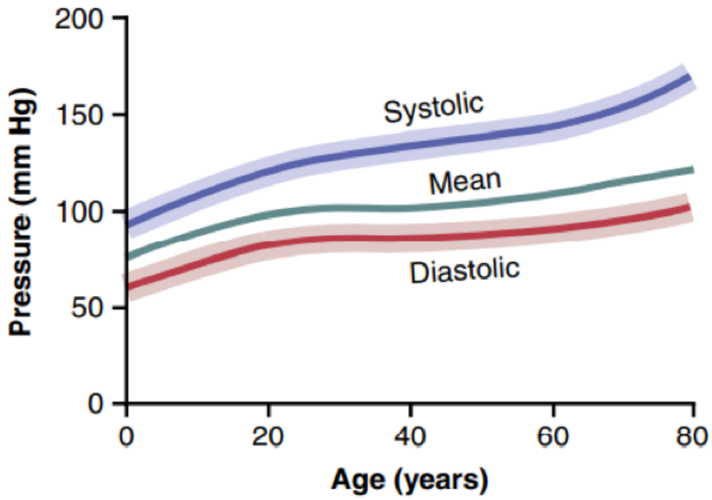
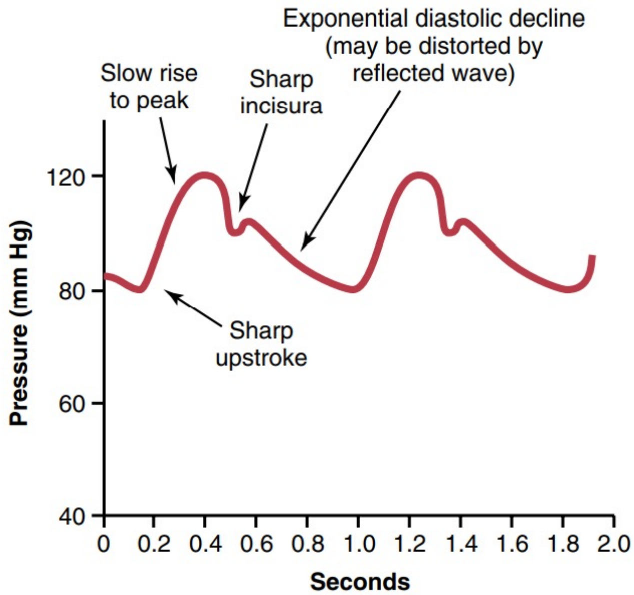
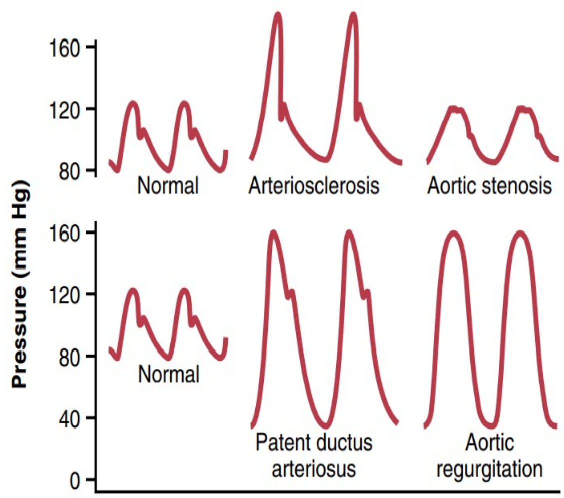


Arterial pressure pulsation

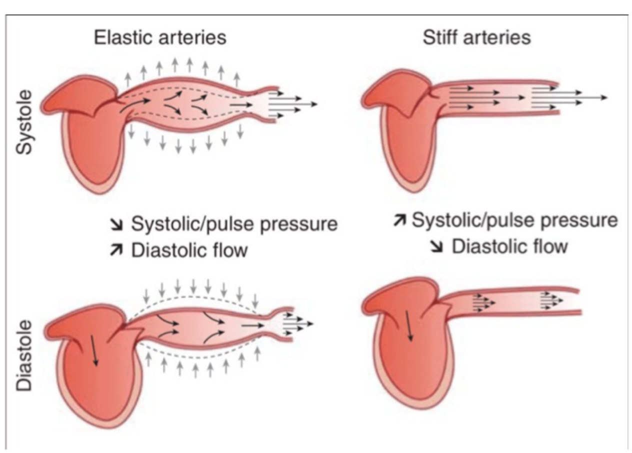
- The compliance of the arterial tree normally reduces the pressure pulsations to almost no pulsations by the time the blood reaches the capillaries; therefore, tissue blood flow is mainly continuous with very little pulsation.
- Two **major factors affect the pulse pressure**: (1) the **stroke volume** output of the heart; and (2) the **compliance** (total distensibility) of the arterial tree. A third less important factor is the character of ejection from the heart during systole.

• **Pulse pressure ≈ Stroke volume/arterial compliance**



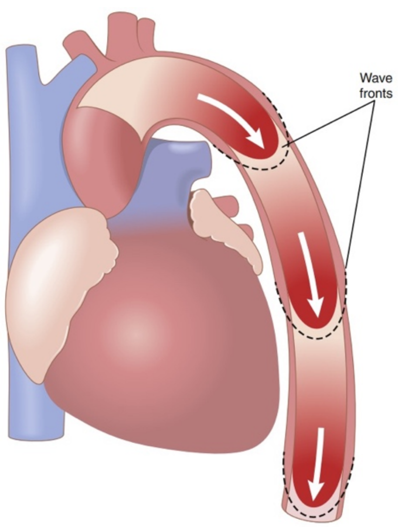


Aortic pressure pulse contours



Transmission of pressure pulses to the arteries

• When the heart ejects blood into the aorta during systole, only the proximal portion of the aorta initially becomes distended because the inertia of the blood prevents sudden blood movement all the way to the periphery. However, the rising pressure in the proximal aorta rapidly overcomes this inertia, and the **wavefront** of distention spreads farther and farther along the aorta. This phenomenon is called **transmission of the pressure pulse in the arteries.**



Velocity of pressure pulse

• The velocity of pressure pulse transmission is 3 to 5 m/sec in the normal aorta, 7 to 10 m/sec in the large arterial branches, and 15 to 35 m/sec in the small arteries.

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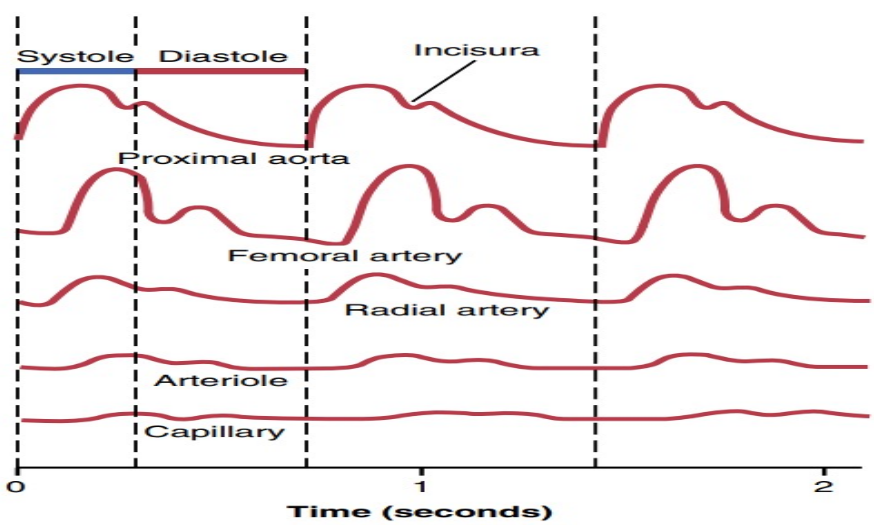
• In general, **the greater the compliance of each vascular segment, the slower the velocity**.

Transmission of pressure pulses to the arteries

• In the aorta, the **velocity of transmission of the pressure pulse is 15 or more times the velocity of blood flow** because the pressure pulse is simply a moving wave of pressure that involves little forward total movement of blood volume.

• The intensity of pulsation becomes progressively less in the smaller arteries, arterioles and, especially, capillaries.

• In fact, only when the aortic pulsations are extremely large or the arterioles are greatly dilated can pulsations be observed in the capillaries



Damping of pressure pulses

• This progressive diminution of the pulsations in the periphery is called damping of the pressure pulses.

• The **cause** of this damping is twofold: (1) **resistance to blood movement in the vessels.** The resistance damps the pulsations because a small amount of blood must flow forward at the pulse wave front to distend the next segment of the vessel; the greater the resistance, the more difficult it is for this to occur.

- (2) **compliance of the vessels**: The compliance damps the pulsations because the more compliant a vessel, the greater the quantity of blood required at the pulse wave front to cause an increase in pressure.
- Therefore, the degree of damping is almost directly proportional to the product of resistance times compliance.