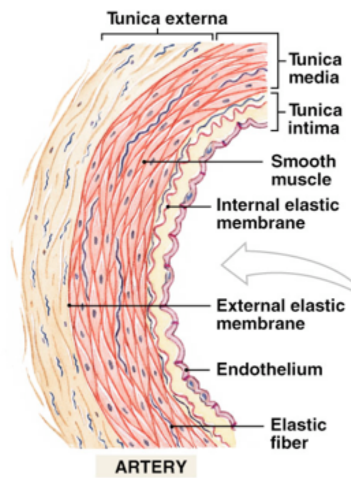
Chapter 21
CV Circulation

The 5 classes of vessels

Arteries:	Conduct blood away from the heart
Arterioles:	"Resistance vessels" Conduct blood to capillaries Contain smooth muscle
Capillaries:	Where exchange occurs (between blood and ICF) Connects arterioles to venules
Venules:	Small collecting vessels Receive blood from capillaries
Veins:	Capacitance vessels Return blood to heart

The Tunics (layers of vessel wall)

- Tunica Interna (also called tunica intima). It is made up of endothelium and underlying CT. It has an *internal elastic membrane* in arteries.
- Tunica Media is made up of smooth muscle. It contracts to constrict the lumen, and relaxes to dilate the lumen. The thickest layer is in the small arteries, and has an *external elastic membrane* in arteries.
- Tunica Externa (also called tunica adventitia). It is a CT sheeth made up of collagen and some elastic fibers (arteries), and in veins made up of collage, elastic fibers and smooth muscle cells.

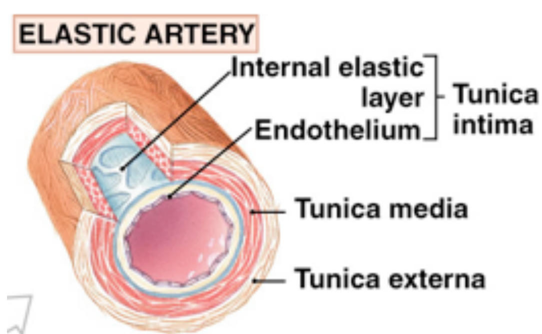


Note that the walls of arteries and veins have their own blood supply: the vaso vasorum.

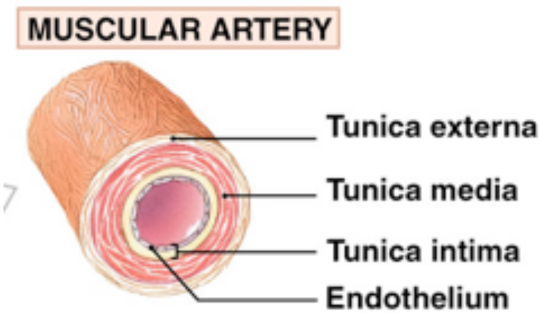
The Arterial System

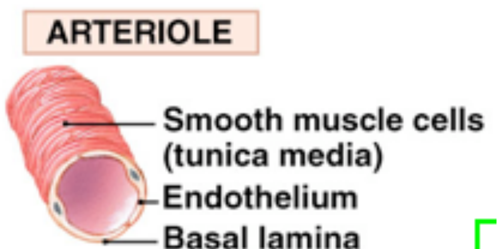
The arterial system is a divergent network of vessels that all branch off from the aorta. As the diameter decreases, the surface area increases due to the growing numbers of smaller and smaller vessels.

<u>The large arteries</u>, called the "elastic arteries" or "conducting arteries" are the trunks. They are large in diameter (about 1inch), and conduct a large volume of blood away from the heart (aortic trunk, pulmonary trunk). These vessels are very resistant due to a lot of elastic fibers. Their elastic rebound provides a "pressure reservoir." Systole stretches the elastic of the artery. The initial ejection of blood from the heart propels 25mL of the 75mL…what happens to the remaining 50mL? It is projected along as the arteries rebound from the stretch. This keeps the flow constant.



The Medium/Small Arteries are also called The Musclar or Distributing Arteries. These are kind of like a hybrid between the elastic and the arterioles. They distribute blood flow to and within the organs. The smooth muscle of these vessels is primarily controlled by the SNS and hormones. The size of these vessels range from about .5 mm up to .5 cm. Examples of these are the external carotid, brachial and mesenteric.



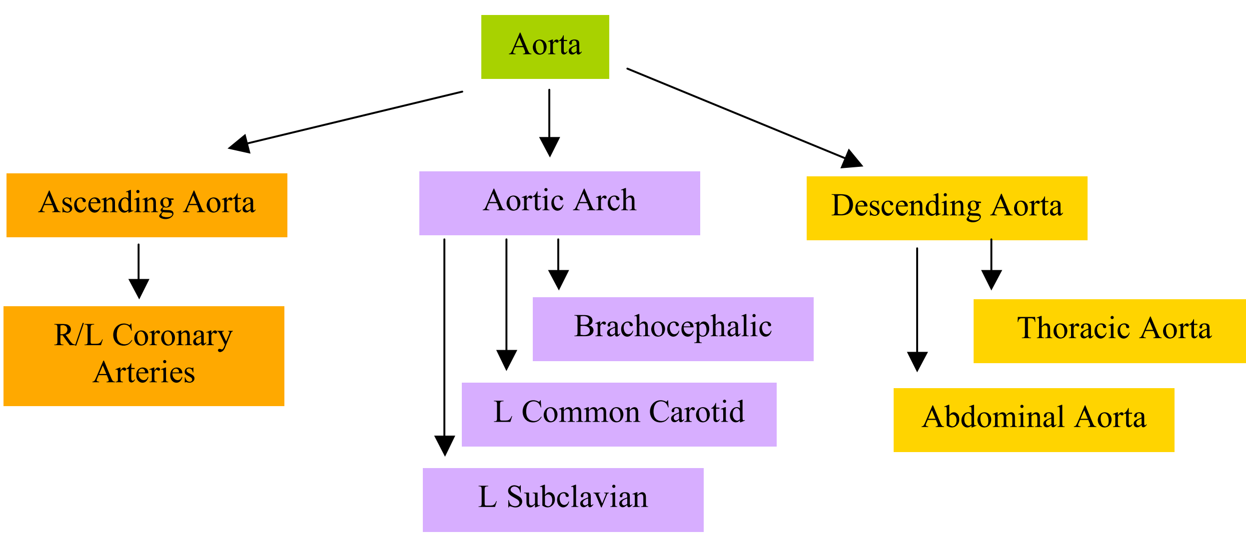


The Arterioles are also called the Resistance Vessels. They have small diameters which provide high resistance to blood flow, and it can be manipulated to redirect/redistribute blood flow wherever it is needed most. The smooth muscle here is mainly controlled by the SNS, hormones and even local tissue conditions. The arterioles lack a tunica exeterna, but have the tunica media and the tunica interna.

Disorders of the arterial vessels

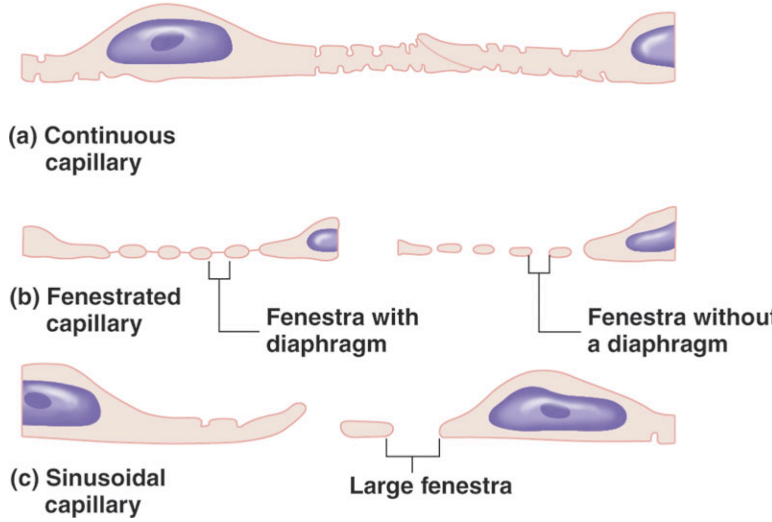
- Aneurysm = bulging in weakened vessel wall that may rupture
- Arteriosclerosis = thickening/toughening of the arterial walls, they lose their elasticity and the lumen narrows increasing resistance to blood flow
- Artherosclerosis = a form of arteriosclerosis associated with lipid deposition and plaque formation in the tunica media of the arterial wall. It may lead to blood clot formation if endothelial lining is disrupted. A treatment for this is called percutaneous transluminal angioplasty.

Aortic Branching (just some of it!)



Capillaries

Capillaries are the most important component of the circulatory vessels. They are essentially composed of an endothelial tube. There are 3 types:

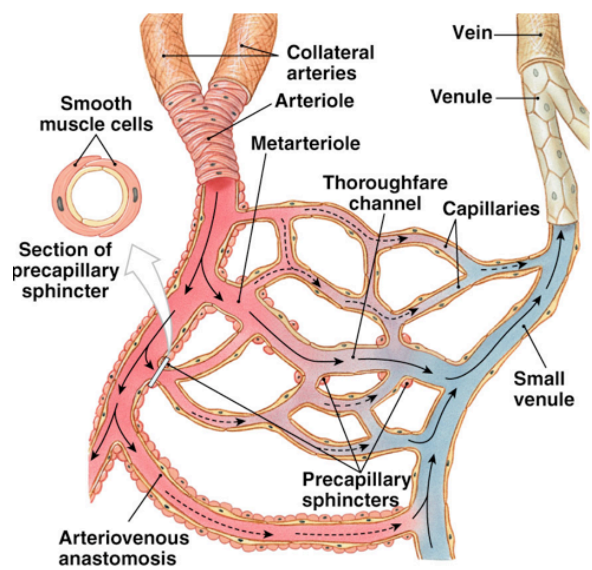


Continuous capillaries are made up of a continuous endothelial lining with small intercellular clefts of about 4nm. They are found in all tissues except epithelia and cartilage! They permit diffusion of water, small solutes and lipophilic substances. No cells or proteins!

Fenestrated capillaries have pores sized between 10-100 nm that permeate the endothelial cells. This allows diffusion of all the above items, plus small proteins. (still no cells allowed through!) They are found in organ tissues.

Sinusoidal capillaries are also called "discontinuous capillaries". They have huge intercellular clefts and pores which permit everything above plus large proteins and blood cells to pass through! They are in the liver and bone marrow.

One arteriole feeds dozens of capillaries (and one venule drains dozens of capillaries.) The amount of blood flowing into each capillary is regulated by precapillary sphinctors. When sphinctors are constricted in the metarteriole thoroughfare channel then you have a vascular shunt—it bypasses the capillaries. Arteriovenous anastomoses are a direct link between the arteriole and the venule…it is another way to bypass the capillaries.



2 ways to bypass capillaries:

1. Arteriovenous anastomoses
2. Vascular shunt

Capillary Exchange

Capillaries are ideal for exchange because:

- They are extremely thin (just endothelial cells and basal lamina)
- They have a short diameter
- They have a huge surface area (this reduces velocity of blood flow)
- They have extensive branching (most cells within .1mm)

Substances move across the capillary wall by diffusion, filtration and reabsorption.

Filtration = out of the capillary
Reabsorption = into the capillary

Diffusion utilizes a concentration gradient, while bulk flow utilizes a pressure gradient. The two forms of bulk flow are filtration and its opposite, reabsorption. With bulk flow, dissolved substances are moving with water through clefts or pores, which are fluid-filled channels. Substances that are too large to fit thorugh the pores or clefts will be left behind…"filtered out."

The pressure gradient is the difference between the outward directed fluid pressure and the inward directed fluid pressures.

The resulting gradient is called the Net Filtration Pressure, or NFP.

The outward directed forces (out of the capillary into IF) are:

- Capillary hydrostatic pressure (capillary BP)
  - HP_c = 35mmHg at the arterial end
  - HP_c = 18 mmHg at the venous end
- Interstitial oncotic prssure
  - O_{IF} = 0mmHg

The inward directed forces (into the capillary from IF) are:

- Interstitial fluid hydrostatic pressure
  - HP_{IF} = 0mmHg
- Capillary oncotic prssure
  - O_c = 25mmHg (due to a lot of plasma proteins)

$$NFP = (HP_C + OP_{IF}) - (HP_{IF} + OP_C)$$

A positive NFP results in filtration. This occurs along the first half of the capillary length. A negative NFP results in reabsorption. This occurs along the second half of the capillary length. Note that net filtration is slighty larger than net reabsorption, so about 3-4L of fluid per day escapes the capillaries, but is returned to the blood by the lymphatic system.

Benefits of these net filtration fluid movements from the blood through the IF thorugh the lymphatics and back to the blood are:

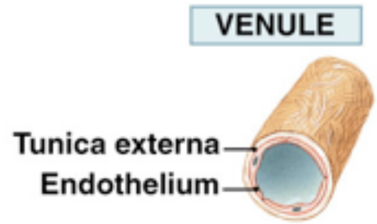
- Enhanced delivery of substances to tissues
- Continuous mixing of ECF divisions
- Transport of larger insoluble substances to the blood
- Flushes microbes and toxins into the lymphatic tissues

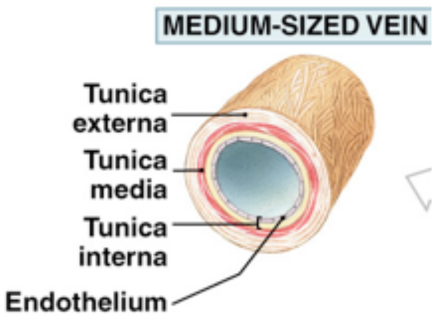
What would be the consequence of reduced plasma proteins due to liver damage? Oncotic pressure would be off, so there would be less filtrate and less going through the lymphatic system? Could there be a buildup somewhere? An edema or something?

Venous System

The venous system is a convergent network of vessesl whose diameter get bigger as the surface area decreases.

The VENULES are the collecting vessels…they collect blood from the capillaries. They are made up of a tunica externa and endothelium. They contain one-way valves.

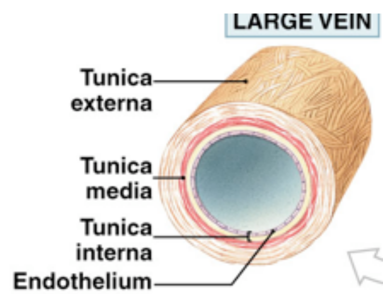




Next they become the SMALL/MEDIUM veins which are made up of a thin tunica media, and a thick tunica externa. These veins contain one-way valves, just like the venules. Because gravity is often stronger than the low venous blood pressure, the valves are needed to prevent backflow into the capillaries.

It is the valves, plus the skeletal muscle pump, that prevent blood pooling and increase venous return. Gotta exercise!!! Disorders of the valves include varicose veins and hemorrhoids. Women tend to get more varicose veins than men, but not sure why.

The LARGE VEINS are the capacitance vessels. They have all three tunics, and a thicker tunica externa than media. Note that they are NOT elastic like the arteriesExamples are the Vena Cava and the major tributaries.



Major veins are the coronary sinus, inferior VC and superior VC.

Veins are very distensible/stretchy due to their large lumens and thin walls. The thin walls are OK because there is less pressure in the veins than in the arteries. Note that veins are 8x more stretchy than arteries with an equal change in pressure. This allows veins to act as a blood reservoir and accommodate large changes in blood volume depending on fluid status and metabolic demands of the body.

The distribution of blood at rest:

- 1/3 is in the heart and the systemic/pulmonary arteries and capillaries
- 2/3 is in the systemic veins
- 4% is in the pulmonary veins

Venous Return is a large pressure gradient between the aorta and the vena cava…a difference of about 9-10 mmHg

During exercise, blood is “mobilized” from the veins so VR and CO increase, and a larger portion of blood flows through the arteries/capillaries as they dilate to meet this increased demand. Skin blood flow increases dramatically to dispel heat, brain stays the same, the amount of blood in the heart increases and kidney and abdomen decrease.

During severe dehydration/hemorrhaging, there is venoconstriction in the liver, skin and lungs to mobilize 1/3 of the venous blood into general circulation. Wow!

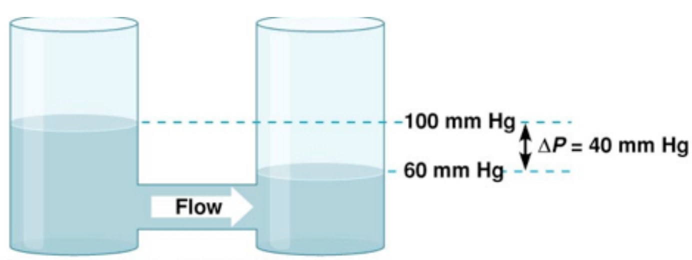
Other advantages of greater capacitance:
- Blood reservoir
- Thermoregulation
- Can drain veins into lymphatic system

5 Systems that Maintain/Enhance VR

Skeletal muscle pump:	Leg muscles are always working when standing. Works more when exercising
Venous one-way valves:	Can become weakened, produce varicose veins
Respiratory pump:	V is inversely proportional to 1/P
Veno motor tone:	Controlled by SNS Alpha receptors in smooth muscle bed of the veins E/NE cause venoconstriction
Cardiac suction:	During systole the AV valve is closed and pulls slightly into the Rt Ventricle. This increases the surface area of the right atrium. Pressure drops, so more blood enters the RV.

Dynamics of Circulation

There is an interralation between pressure, flow and resistance. PRESSURE GRADIENTS in the CV SYSTEM:
- Pressure gradient across systemic circulation is greater than pressure gradient across pulmonary circulation. The pressure gradient across the arteries is greatest
- Pressure gradients drive flow



(a) Flow = 20 mL/min

RESISTANCE IN THE CV SYSTEM
- Pressure gradient in systemic circuit much greater than for pulmonary circuit
- Flow through both circuits equal (*~5 L/min at rest*)
- Flow = ΔP/R, thus R= ΔP/Flow
- Resistance through pulmonary circuit much less than through systemic circuit

FACTORS AFFECTING BLOOD FLOW

1. Poiseuilles Law states that Resistance = $8nL/r^4$

   But since you can basically discount the vessel length as being a constant, and the velocity as being a constant, and since the 8 is a fudge-factor number for velocity and length, the equation ends up being Resistance=$1//r^4$

   What this means is that resistance is proportional to the amount of blood in contact with the vessel walls, which is proportional to the viscocity, length and radius. We rely on the manipulation of the radius to rapidly adjust changes in resistance. A small decrease or increase in radius causes HUGE CHANGES!

2. TPR = Total Peripheral Resistance.
   a. Total BF --- CO=the change in Pressure/TPR
3. CO = total BF through circulation in Liters per minute. This is total bloodflow versus organ bloodflow.

BLOOD PRESSURE

BP is measured in mmHg. It is a measure of the force exerted on the wall of the vessel…called "hydrostatic pressure." When measuring blood pressure, you are measuring turbulent vs. laminar flow. What you hear are the "Korotkoff sounds" using the blood pressure cuff.

SYSTEMIC BLOOD PRESSURE

- Systemic BP is measured as Systolic/Diastolic
- The BP is pulsatile in the arteries.
- Systolic – Diastolic = Pulse pressure
- MAP (Mean Arterial Pressure) = 2/3 DBP + 1/3 SBP ~ 93 mmHg
- Disorders of BP
  - Hypertension is > 140/90. In hypertension, increased afterload causes the heart muscles to hypertrophy which increases the metabolic demands of the myocardium, but supply can't keep up so it leads to ischema and MI ☹
  - Hypotension is low BP which causes decreased bloodflow to the brain making one feel dizzy and faint.
- Other Systemic Blood Pressures
  - Arterial BP is measured in the Aorta at 100 mmHg and in the arterioles at 35 mmHg. The change in pressure here is about 65 mmHg. Note that pulse pressure is lowered from the aorta to the arterioles. The PP is dampened by elastic rebound of the arteries. The pressure falls as blood overcomes more and more resistance.
  - Capillary BP is the same as HP_C. At the arteriole end this is 35 mmHg. At the venule end is it 18 mmHg…so the change in pressure is ~ 17 mmHg.
  - Venous BP has a pressure of 18 mmHg at the venules and 0 mmHg at the Right Atrium, so the change in pressure is about 18 mmHg.
    - The low pressure gradient is helped by low resistance, one-way valves, skeletal muscle pumps, respiratory pump and venoconstriction.

- Resistance (due to vessel radius) is THE MOST IMPORTANT factor influencing blood pressure. Resistance is largely controlled by the SNS:
  - Vasomotor tone
  - Increased SNS activity will decrease the radius (constriction) which leads to increased resistance when NE binds to the alpha-receptors
  - Decreased SNS activity will increase the radius (dilation), which leads to lowered resistance.
  - EXCEPT: the blood vessels in the heart/skeletal muscle have lots of beta-receptors for dilation!!!