The Heart

Pathway of blood flow:

Inferior vena cava → RIGHT ATRIUM → Tricuspid valve → RIGHT VENTRICLE → Pulmonary semilunar valve → Pulmonary arteries → Lungs → Pulmonary veins → LEFT ATRIUM → Bicuspid valve → LEFT VENTRICLE → Aortic semilunar valve → Aorta

Deoxygenated

Oxygenated
Angiogenesis is the physiological process involving the growth of new blood vessels from pre-existing vessels.

- **Angiogenesis takes place:**
  - As the number of vessels to a region increases
  - When existing vessels enlarge
  - When a heart vessel becomes partly occluded
  - Routinely in people in high altitudes, where oxygen content of the air is low
  - New tissue or extended tissue [abnormal as cancer]
  - Wound healing and in granulation tissue
**Vasculogenesis** is the de novo formation of blood vessels during embryogenesis.

**Hemangioblast angiogenic precursors** develop and migrate to the sites of vascularization.
- These differentiate into endothelial cells that associate to form a primitive vascular plexus;
- with time and the influence of local genetic, metabolic, and hemodynamic factors, this network of cells *remodels* (through pruning and/or vessel enlargement) into the definitive vascular system

- The various isoforms of **vascular endothelial growth factor (VEGF)** are the primary growth factors involved in this process.
- Subsequent stabilization of the endothelial tubes during development (and induction of endothelial cell quiescence) also critically requires the recruitment of pericytes and smooth muscle cells, a process that involves *angiopoietin 1* binding to endothelial cell *Tie2 receptors*
**Arteriogenesis** refers to the **remodeling of existing arteries** in response to:

- chronic changes in pressure or flow,
- results from an interplay of endothelial cell–and smooth muscle cell–derived factors

**Angiogenesis (or neovascularization)** constitutes the process of new vessel formation in the mature organism
The healthy body controls angiogenesis through a series of "on" and "off" switches:

- The main "on switches" are known as angiogenesis-stimulating growth factors
- The main "off switches" are known as angiogenesis inhibitors
The Distribution of Blood

- Systemic venous system: 64%
- Large veins: 18%
- Large venous networks (liver, bone marrow, skin): 21%
- Pulmonary circuit: 9%
- Pulmonary veins: 4%
- Pulmonary arteries: 3%
- Pulmonary capillaries: 2%
- Heart: 7%
- Aorta: 2%
- Elastic arteries: 4%
- Muscular arteries: 4%
- Arterioles: 2%
- Systemic capillaries: 7%
- Venules and medium-sized veins: 25%
- Systemic arterial system: 13%
Vessel Structure/Function

• **At rest**
  - 60% of **blood volume** is located in veins and venules
  - venous system serves as reservoirs for blood
  - particularly veins of the abdominal organs and the skin

• **ANS regulates volume distribution**
  - vasoconstriction
  - vasodilation
  - diverts blood to areas with increased metabolic needs

Compare to Cardiac Output figures
Blood Distribution at Rest

CO = 5 L/min

≈ 0.75 L/min
Blood Distribution -- Exercise

Using cardiac reserve
Blood Vessels

• Blood is carried in a closed system of vessels that begins and ends at the heart
• Arteries carry blood away from the heart, veins carry blood toward the heart
• Capillaries contact tissue cells and directly serve cellular needs
An Overview of Cardiovascular Physiology

Cardiac Output

Venous Return

Venous Pressure

Regulation (Neural and Hormonal)

Arterial Blood Pressure

Peripheral Resistance

Capillary Pressure

Capillary exchange

Interstitial fluid
Type of blood vessels

- Arteries [small[arterioles], medium, large]
- Veins [small[veinules], medium, large]
- Capillaries
- Lymphatics
The Vascular Anastomosis

1. Arterial anastomosis arterial arch: - provide collateral supply to some organs and tissues, e.g., skeletal muscles

2. Venous anastomosis venous arch
   : - most common, e.g., deep and superficial veins in limbs and head

3. Arteriovenous anastomosis : arteriolovenular anastomosis

4. Venous plexus

5. Collateral anastomosis collateral vessel collateral circulation
Generalized Structure of Blood Vessels

- Arteries and veins are composed of three tunics –
  - tunica interna,
  - tunica media,
  - tunica externa
- **Lumen** – central blood-containing space surrounded by tunics
- Capillaries are composed of endothelium with sparse basal lamina

(A), tunica intima; (B), internal elastic lamina; (C), tunica media; (D), external elastic lamina; (E), tunica externa.
The arterial wall is composed of three main layers or tunics.

- **Tunica intima** (internal tunic) consisting of:
  - endothelium (single lining layer of endothelial cells) **sub-endothelial** connective tissue basement membrane layer **inner elastic limiting membrane** (elastic lamina, which after fixation appears undulating).

- **Tunica media** (middle tunic) consisting of:
  - circular smooth muscle (or spiral)
  - concentric elastic lamina (formed by the smooth muscle cells).
  - Smooth muscle and elastic fiber layer, regulated by sympathetic nervous system
  - Controls vasoconstriction/vasodilation of vessels

- **Adventitia = tunica externa** (outer layer) composed of:
  - Collagen fibers that protect and reinforce vessels
  - Larger vessels contain vasa vasorum
  - connective tissue surrounding the vessel **outer elastic limiting membrane** (on the border between the Tunica media and the Adventitia Vasa vasorum).
  - These are small blood vessels supplying oxygen and nutrients to the wall of the artery.
  - The blood flow in the arterial lumen is too great for exchange of oxygen or nutrients.
Vasa vasorum
Nerve
Tunica adventitia
External elastic membrane
Tunica intima
Smooth muscle
Internal elastic membrane
Tunica media
Basement membrane
Lamina propria (smooth muscle and connective tissue)
Endothelium
Elastic Artery

• The elastic artery is a specialized type of artery designed for distension and elasticity.

• The largest of these also have connective tissue underneath the endothelium.

• A good example of an elastic artery is the aorta.

• Thick-walled arteries near the heart; the aorta and its major branches
  • Large lumen allow low-resistance conduction of blood
  • Contain elastin in all three tunics
  • Withstand and smooth out large blood pressure fluctuations
  • Serve as pressure reservoirs
Muscular arteries –
• distal to elastic arteries; deliver blood to body organs
  • Have thick tunica media with more smooth muscle
  • Active in vasoconstriction
• Blood vessels contain each of the major tissue types: epithelia (called endothelia), connective tissue, muscle, and nerve fibers.
• The **Tunica intima** is a simple endothelial layer, made of **simple squamous cells**.
• Underneath is an internal elastic membrane, the **elastica interna**.
• Then, there is a smooth muscle layer, **the tunica media**.
• This is followed by a poorly defined outer elastic layer.
• Finally, the **Adventia is connective tissue (loose) that blends into the surrounding connective tissue.**
Muscular artery
Artery elastin & eosin

- tunica intima
- internal elastic lamina
- tunica media
- fine elastic fibres
- external elastic lamina
- tunica adventitia

Muscular artery

TI

IEM

TM

TA
Arterioles

- Arterioles can be differentiated from arteries by the numbers of layers of smooth muscle.
- Usually there are no more than 6 layers.
- The smaller of the two vessels is often called a "precapillary arteriole" because of the number of smooth muscle layers.
• Arterioles – smallest arteries; lead to capillary beds
  • Control flow into capillary beds via vasodilation and constriction
Blood Vessels

Arteries: main transporters of oxygenated blood
Arterioles: diameter is adjusted to regulate blood flow
Capillaries: diffusion occurs across thin walls
• Capillaries are tiny vessels lined by a single layer of endothelial cells.
• Capillary accommodates only one blood cell.
• Capillaries are the smallest blood vessels
  • Walls consisting of a thin tunica interna, one cell thick
  • Allow only a single RBC to pass at a time
  • Pericytes on the outer surface stabilize their walls
• There are three structural types of capillaries: **continuous, fenestrated, and sinusoids**
Many capillaries have inconspicuous, elongated cells, similar in appearance to embryonic mesenchymal cells, associated with them. These cells, known as pericytes, or perivascular cells, are quite difficult to see in most histological preparations. These pericytes appear to have important roles in repair of blood vessels and connective tissue after injury. They have the potential to develop into fibroblasts, smooth muscle cells and may even be phagocytic.

Endothelial cells are known to produce a variety of local factors that are important in the functioning of the cardiovasystem. These include nitric oxide.

- It serves to support these vessels,
- It can differentiate into a fibroblast, smooth muscle cell, or macrophage if required.
- In order to migrate into the interstitium, the pericyte has to break the barrier, formed by the basement membrane, which can be accomplished by fusion with the membrane.
- They are important in blood-brain barrier stability as well as angiogenesis.
- They have been implicated in blood flow regulation at the capillary level.
- Their expression of smooth muscle actin (SMA) and desmin, two proteins found in smooth muscle cells, and their adherence to the endovascular cells makes them very strong candidates for blood flow regulators in the microvasculature.
Blood Vessel Anatomy

- **Continuous Capillary**
  - Complete basal lamina
  - Continuous endothelial lining

- **Discontinuous Capillary**
  - Incomplete basal lamina
  - Fenestrated endothelial lining

- **Fenestrated Capillary**
  - Complete basal lamina
  - Fenestrated endothelial lining

---

**Table 19.1: Summary of Blood Vessel Anatomy**

<table>
<thead>
<tr>
<th>Vessel Type/ Illustration*</th>
<th>Average Lumen Diameter (D) and Wall Thickness (T)</th>
<th>Relative Tissue Makeup</th>
</tr>
</thead>
</table>
| Elastic artery               | D: 1.5 cm  
T: 1.0 mm                                  | Endothelium Brown Tissue Smooth Muscle Connective Tissue |
| Muscular artery             | D: 6.0 mm  
T: 1.0 mm                                  | Endothelium Brown Tissue Smooth Muscle Connective Tissue |
| Arteriole                   | D: 3.7 mm  
T: 0.6 mm                                  | Endothelium Brown Tissue Smooth Muscle Connective Tissue |
| Artery                      | D: 3.0 mm  
T: 0.5 mm                                  | Endothelium Brown Tissue Smooth Muscle Connective Tissue |
| Capillary                   | D: 9.0 μm  
T: 0.6 μm                                  | Endothelium Brown Tissue Smooth Muscle Connective Tissue |
| Vessel                      | D: 20.0 μm  
T: 1.0 μm                                  | Endothelium Brown Tissue Smooth Muscle Connective Tissue |
| Vein                        | D: 5.0 mm  
T: 0.5 mm                                  | Endothelium Brown Tissue Smooth Muscle Connective Tissue |

*Size relationships are not proportional; smaller vessels are drawn relatively larger so detail can be seen. See column 2 for actual dimensions.
### Continuous Capillaries
- Continuous capillaries are abundant in the skin and muscles
  - Endothelial cells provide an uninterrupted lining
  - Adjacent cells are connected with tight junctions
  - Intercellular clefts allow the passage of fluids
- Continuous capillaries of the brain:
  - Have tight junctions completely around the endothelium
  - Constitute the blood-brain barrier

### Fenestrated Capillaries
- Found wherever active capillary absorption or filtrate formation occurs (e.g., small intestines, endocrine glands, and kidneys)
- Characterized by:
  - An endothelium riddled with pores (fenestrations)
  - Greater permeability than other capillaries

### Sinusoids
- Highly modified, leaky, fenestrated capillaries with large lumens
- Found in the liver, bone marrow, lymphoid tissue, and in some endocrine organs
- Allow large molecules (proteins and blood cells) to pass between the blood and surrounding tissues
- Blood flows sluggishly, allowing for modification in various ways

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**Diagram:**

- **(a)** Capillary with structures labeled:
  - Pericyte
  - Red blood cell in lumen
  - Intercellular cleft
  - Endothelial cell
  - Pinocytotic vesicles
  - Basement membrane
  - Tight junction
  - Endothelial nucleus

- **(b)** Fenestrated capillary:
  - Pericyte
  - Pinocytotic vesicles
  - Red blood cell in lumen
  - Fenestrations (pores)
  - Intercellular cleft
  - Endothelial cell

- **(c)** Sinusoid:
  - Pericyte
  - Red blood cell in lumen
  - Large intercellular cleft
  - Nucleus of endothelial cell
  - Tight junction
  - Incomplete basement membrane
Capillary Beds

• A microcirculation of interwoven networks of capillaries, consisting of:
  • **Vascular shunts** – metarteriole–thoroughfare channel connecting an arteriole directly with a postcapillary venule
  • **True capillaries** – 10 to 100 per capillary bed, capillaries branch off the metarteriole and return to the thoroughfare channel at the distal end of the bed
Capillary Exchange

CHP = Capillary hydrostatic pressure  
BCOP = Blood colloid osmotic pressure  
NFP = Net filtration pressure

3.6 l/day reabsorbed into lymphatic capillaries

Arteriole

24 l/day moves out of capillaries

25 mm Hg

No net fluid movement

20.4 l/day reabsorbed

NFP = +10 mm Hg

NFP = 0

NFP = -7 mm Hg

CHP > BCOP
Fluid forced out of capillary

CHP = BCOP
No net movement of fluid

BCOP > CHP
Fluid moves into capillary

Returned to circulation

Venule
Blood Flow Through Capillary Beds

- **Precapillary sphincter**
  - Cuff of smooth muscle that surrounds each true capillary
  - Regulates blood flow into the capillary

- **Blood flow is regulated by vasomotor nerves and local chemical conditions**
Capillary Beds
Gas Exchange Between Alveoli and Capillaries

Capillary bed drainage by lymphatic capillary

- Lymphatic capillary
- Tissue fluid (mostly colloidal substances) enters lymphatic capillary
- Capillary
- Tissue fluid enters capillary
- Arteriole
- High pressure
- Plasma exuded
- Tissue fluid
- Low pressure
- Tissue cells
- Red cell
- Venule

Capillary bed following loss/disruption of local lymphatics

- Capillary
- Build-up of tissue fluid causing swelling (lymphoedema)
- Arteriole
- Tissue cells
- Venule

from the pulmonary artery
to the pulmonary vein
capillary
alveolar membrane
respiratory membrane
surfactant fluid
O$_2$
CO$_2$

Oxygen diffuses into the red blood cells
Carbon dioxide diffuses into the alveolus

Fig.
The movement of fluid between capillaries and the interstitial fluid. Fluids flow out of a capillary at the upstream end near an arteriole and reenters a capillary downstream near a venule. The direction of fluid movement across the capillary wall at any point depends on the difference between two opposing forces: blood pressure and osmotic pressure.
VEINS
Venous System: Venules

- Venules are formed when capillary beds unite
  - Allow fluids and WBCs to pass from the bloodstream to tissues
- Postcapillary venules – smallest venules, composed of endothelium and a few pericytes
- Large venules have one or two layers of smooth muscle (tunica media)

- Veins are distinguished by their thinner wall, valves, collapsed state.
- The tunica media does not look as well organized as that in the artery or arteriole.
Venous System: Veins

- Veins are:
  - Formed when venules converge
  - Composed of three tunics, with a thin tunica media and a thick tunica externa consisting of collagen fibers and elastic networks
  - Capacitance vessels (blood reservoirs) that contain 65% of the blood supply
Veins have much lower blood pressure and thinner walls than arteries.

To return blood to the heart, veins have special adaptations:
- Large-diameter lumens, which offer little resistance to flow
- Valves (resembling semilunar heart valves), which prevent backflow of blood

Venous sinuses – specialized, flattened veins with extremely thin walls (e.g., coronary sinus of the heart and dural sinuses of the brain)
• The largest veins of the abdomen and thorax do contain some subendothelial connective tissue in the tunica intima, but both it and the tunica media are still comparatively thin.
• Collagen and elastic fibres are present in the tunica media. The tunica adventitia is very wide, and it usually contains bundles of longitudinal smooth muscle.
• The transition from the tunica adventitia to the surrounding connective tissue is gradual.
• Valves are absent.

Vasa vasorum are more frequent in the walls of large veins than in that of the corresponding arteries - probably because of the lower oxygen tension in the blood contained within them.
Muscle contracts
Valve closed

Muscle relaxes
Valve open

Blood propelled forward by muscle contractions and, possibly, by gravity

Valve open

Back pressure due to contractions of atria, contractions of muscles, and, possibly, gravity
Types of varicose veins

- Spider veins
- Reticular varices
- Varicose vein trunk
VERICOSE VEINS
# Differences Between Arteries and Veins

<table>
<thead>
<tr>
<th></th>
<th>Arteries</th>
<th>Veins</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Delivery</strong></td>
<td>Blood pumped into single systemic artery – the aorta</td>
<td>Blood returns via superior and interior venae cavae and the coronary sinus</td>
</tr>
<tr>
<td><strong>Location</strong></td>
<td>Deep, and protected by tissue</td>
<td>Both deep and superficial</td>
</tr>
<tr>
<td><strong>Pathways</strong></td>
<td>Fair, clear, and defined</td>
<td>Convergent interconnections</td>
</tr>
<tr>
<td><strong>Supply/drainage</strong></td>
<td>Predictable supply</td>
<td>Dural sinuses and hepatic portal circulation</td>
</tr>
</tbody>
</table>