Blood Vessels

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INTRODUCTION

The main transport systems are the circulatory systems, in which substances are dissolved or suspended in liquid and carried from one part of the body to another in a system of tubes called vessels.

There are two main circulatory systems:

The blood circulatory system (sometimes called the cardiovascular system) and the lymphatic system.

The blood circulatory system is the main method of transporting oxygen, carbon dioxide, nutrients and metabolic breakdown products, cells of the immune and other defence systems, chemical messengers (hormones), other important substances (e.g. clotting factors).

The lymphatic system drains extra-cellular fluid from the tissues returning it to the blood circulatory system after passage through lymph nodes. This system is also involved in absorption of nutrients from the gut.

THE BLOOD CIRCULATORY SYSTEM

There are three types of blood circulatory system, two of which (systemic circulation and pulmonary circulation) depend on a pump, the heart, to push the blood around. The third type of circulation is known as a portal system. These are specialised channels that connect one capillary bed site to another but do not depend directly on a central pump. The largest of these in the human is the hepatic portal system which connects the intestines to the liver.

The systemic circulation transfers oxygenated blood from a central pump (the heart) to all of the body tissues (systemic arterial system) and returns deoxygenated blood with a high carbon dioxide content from the tissues to the central pump (systemic venous system).

As briefly mentioned above the systemic circulation supplies all the body tissues, and is where exchange of nutrients and products of metabolism occurs. All the blood for the systemic circulation leaves the left side of the heart via the aorta.

This large artery then divides into smaller arteries and blood is delivered to all tissues and organs. These arteries divide into smaller and smaller vessels each with its own characteristic structure and function. The smallest branches are called arterioles.

The arterioles themselves branch into a number of very small thin vessels, the capillaries, and it is here that the exchange of gases, nutrients and waste products occurs.

Exchange occurs by diffusion of substances down concentration and pressure gradients.

The capillaries then unite to form larger vessels, venules, which in turn unite to form fewer and larger vessels, known as veins.

The veins from different organs and tissues unite to form two large veins. The inferior vena cava (from the lower portion of the body) and the superior vena cava (from the head and arms), which return blood to the right side of the heart. Thus there are a number of parallel circuits within the systemic circulation.

The pulmonary circulation is where oxygen and carbon dioxide exchange between the blood and alveolar air occurs. The blood leaves the right side of the heart through a single artery, the pulmonary artery, which divides into two - one branch supplying each lung. Within the lung, the arteries divide, ultimately forming arterioles and capillaries; venules and veins return blood to the left side of the heart.

Portal circulation. Normally there is only one capillary bed for each branch of a circuit; however, there are a few instances where there are two capillary beds, one after each other, in series. These are known as portal systems or portal circulations. One example of this is in the liver. Part of the blood supply to the liver is venous blood coming directly from the gastrointestinal tract and spleen via the hepatic portal vein. This arrangement enables the digested and absorbed substances from the gut to be transported directly to the liver, where many of the body's metabolic requirements are synthesised. Thus there are two micro-circulations in series, one in the gut and the other in the liver.

The force required to move the blood through the blood vessels in the two circulations is provided by the heart, which functions as two pumps, the left side of the heart supplying the systemic circulation and the right side the pulmonary circulation.

The systemic circulation is much larger than the pulmonary circulation and thus the force generated by the left side of the heart is much greater than that of the right side of the heart. However, as the circulatory system is a closed system, the volume of blood pumped through the pulmonary circulation in a given period of time must equal the volume pumped through the systemic circulation - that is, the right and left sides of the heart must pump the same amount of blood. In a normal resting adult, the average volume of blood pumped simultaneously is approximately 5 litres per min. As there are approximately 5 litres of blood in an adult, this means that the blood circulates around the body approximately once every minute. During heavy work or exercise, the volume of blood pumped by the heart can increase up to 25 litres per min (or even 35 litres per min in top class athletes).

- Blood is carried in a closed system of vessels that begins and ends at the heart
- The three major types of vessels are arteries, capillaries, and veins
- Arteries carry blood away from the heart, veins carry blood toward the heart
- Capillaries contact tissue cells and directly serve cellular needs

General Structure of Blood Vessels

You have already seen blood vessels of various sizes and types in preparations available in other lab sessions, and you should be aware that the histological appearances of vessels of different sizes (arterioles vs. arteries) and different types (arteries vs. veins) are different from each other. These differences are the result of quantitative variations of a common structural pattern that can be seen in all blood vessels with the exception of capillaries, i.e. the division of the walls of the blood vessels into three layers or tunics.

The tunica intima

delimits the vessel wall towards the lumen of the vessel and comprises its endothelial lining (typically simple, squamous) and associated connective tissue. Beneath the connective tissue, we find the internal elastic lamina, which delimits the tunica intima from

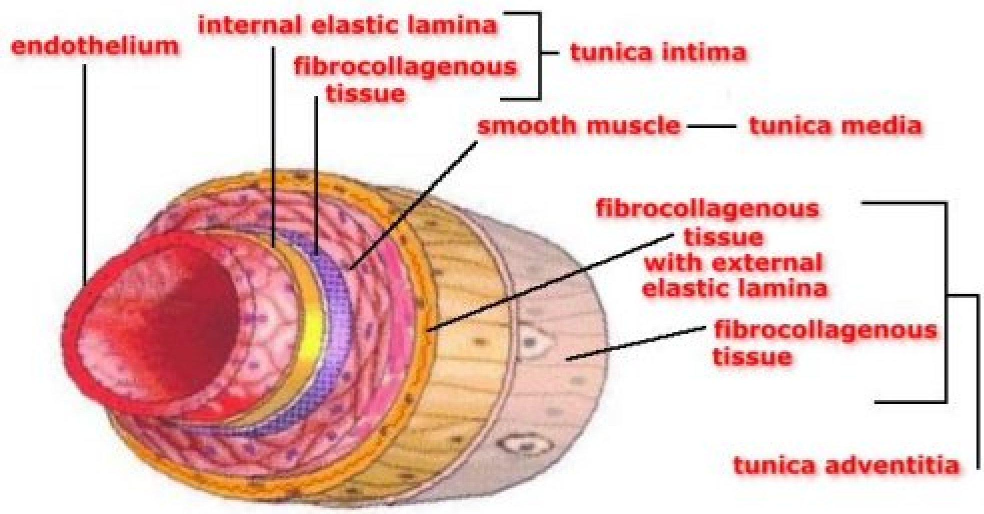
the tunica media.

The tunica media is formed by a layer of circumferential smooth muscle and variable amounts of connective tissue. A second layer of elastic fibers, the external elastic lamina, is located beneath the smooth muscle. It delimits the tunica media from

the tunica adventitia,

which consist mainly of connective tissue fibres. The tunica adventitia blends with the connective tissue surrounding the vessel. The definition of the outer limit of the tunica adventitia is therefore somewhat arbitrary.

- The systemic arterial circulation is an extensive high-pressure system. The structure of its vessels reflects the high pressures to which they are subjected. The output of the left ventricle of the heart is carried in large diameter vessels with a high component of elastic tissue in their walls which smoothes the systolic pressure wave. These are called the large elastic arteries (i.e. the aorta and its large branches such as the carotid, subclavian and renal arteries).
- Moving away from the heart these large elastic arteries branch off into smaller vessels in which the artery walls become



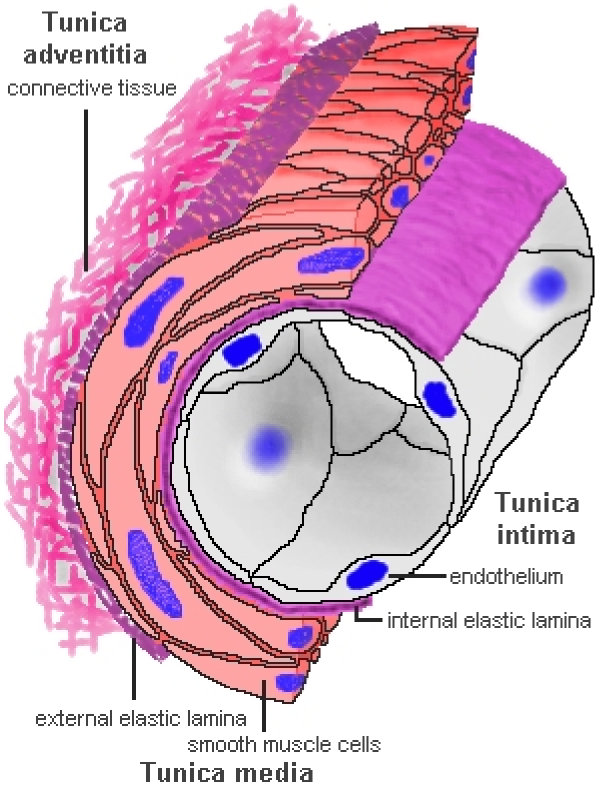
proportionately more muscular.

- **This picture shows a diagrammatic representation of a muscular artery.**
- Elastic arteries are the largest arteries and receive the main output of the left ventricle: thus they are subjected to the high systolic pressures of 120-160 mmHg.
- These large vessels are adapted to smooth out the surges in blood flow, since blood is impelled through them only during the systolic phase of the cardiac cycle. The elastic tissue in their walls provides the resilience to smooth out the pressure wave.

- The intima of large elastic arteries is composed of endothelium with a thin layer of underlying fibrocollagenous tissue.
- Elastic arteries have a thick, highly developed media of which elastic fibres are the main component. These are gathered together in sheets arranged in concentric layers throughout the thickness of the media. In the
- largest artery, the aorta, there are often 50 or more layers.
- The elastic fibres are arranged so that they run in bands around the circumference (circumferentially) rather than along the length of the artery (longitudinally) in order to counteract the tendency for the vessel to over distend during systole.
- When the heart contracts and forces blood into the aorta, the elastic fibres are stretched and, as a result the aorta distends.
- At the end of the left ventricular contraction, the force generated by the heart diminishes and so the force stretching the fibres is removed. As a result of this they tend to return to their starting size.
- The effect of this recoil is to maintain the pressure head and thus force the blood pumped out of the left ventricle away from the heart and into the systemic vascular system.
- This occurs as a result of the conversion of potential energy created by the distension of the elastic wall of the aorta into kinetic energy which continues to move blood away from the heart even in the diastolic phase.
- Return of the elastic fibres from their stretched to unstretched state during diastole maintains a diastolic pressure within the aorta and large arteries of about 60-80 mmHg. It is this mechanism which helps to smooth out the explosive expulsion of blood from the left ventricle into a steady flow throughout the arterial system. Interposed between the elastic layers are smooth muscle cells and some collagen.
- The adventitia of the large vessels carries vasa vasorum and nerves.
- Muscular arteries have a media composed almost entirely of smooth muscle.
- The large elastic arteries gradually merge into muscular arteries by losing most of their medial elastic sheets, usually leaving only two layers, an internal elastic lamina and an external elastic lamina at the junction of the media with the intima and adventitia, respectively.
- Although the walls of muscular arteries are distensible to a certain extent, as they become smaller and smaller with each successive branching the amount of elastic tissue decreases whilst the muscular component proportionately increases.
- In a muscular artery the media is composed almost entirely of smooth muscle. These arteries are therefore highly contractile, their degree of contraction or relaxation being controlled by the autonomic nervous system as well as by endothelium-derived vasoactive substances. A few fine elastic fibres are scattered among the smooth muscle cells, but are not organised into sheets. These are most numerous in the large muscular arteries, which are a direct continuation of the distal end of the elastic arteries.
- Muscular arteries vary in size from about 1 cm in diameter close to their origin at the elastic arteries, to about 0.5 mm in diameter. In the larger arteries there may be 30 or more layers of smooth muscle cells, whereas in the smallest peripheral arteries, there are only 2 or 3 layers. The smooth muscle cells are usually arranged circumferentially at right angles to the long axis of the vessel.
- The internal elastic lamina is commonly a distinct prominent layer, but the external elastic lamina is less well defined, and is often incomplete.

Generalized Structure of Blood Vessels

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



Tunics

- **Tunica interna (tunica intima)**
  - Endothelial layer that lines the lumen of all vessels
  - In vessels larger than 1 mm, a subendothelial connective tissue basement membrane is present
- **Tunica media**
  - Smooth muscle and elastic fiber layer, regulated by sympathetic nervous system
  - Controls vasoconstriction/vasodilation of vessels
- **Tunica externa (tunica adventitia)**
  - Collagen fibers that protect and reinforce vessels
  - Larger vessels contain vasa vasorum

Elastic (Conducting) Arteries

- 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 (Distributing) Arteries and Arterioles

- Muscular arteries – distal to elastic arteries; deliver blood to body organs
  - Have thick tunica media with more smooth muscle
  - Active in vasoconstriction
- Arterioles – smallest arteries; lead to capillary beds
  - Control flow into capillary beds via vasodilation and constriction

Capillaries

- 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

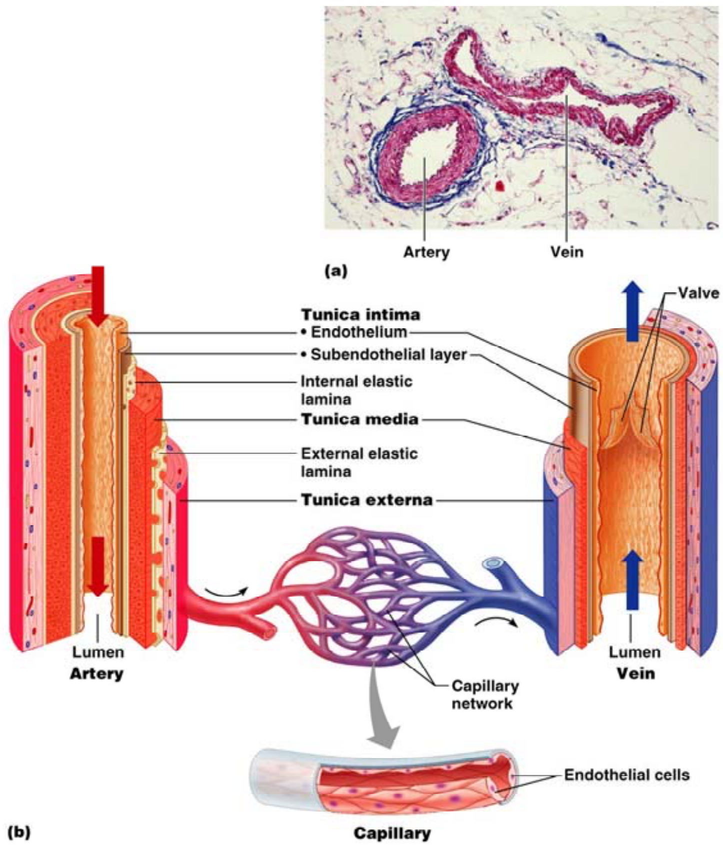


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Figure 19.1

- Variations of Vessel Wall Structure
  - Arteries
- All arterial vessels originate with either the pulmonary trunk (from the right ventricle) or the aorta (from the left ventricle). Specialisations of the walls of arteries relate mainly to two factors: the pressure pulses generated during contractions of the heart (systole) and the regulation of blood supply to the target tissues of the arteries. The tunica media is the main site of histological specialisations in the walls of arteries.
- Vessels close to the heart (aorta, pulmonary trunk and the larger arteries that originate from them) are
- Elastic arteries
  - The tunica intima of elastic arteries is thicker than in other arteries. A layer of loose connective tissue beneath the endothelium (subendothelial connective tissue) allows the tunica intima to move independently from other layers as the elastic arteries distend with the increase in systolic blood pressure. Distension of the walls is facilitated by concentric fenestrated lamellae of elastic fibres in a thick tunica media. In adult humans, about 50 elastic lamellae are found in the tunica media of the aorta. The energy stored in the elastic fibres of the tunica media allows elastic arteries to function as a "pressure reservoir" which

forwards blood during ventricular relaxation (diastole). Smooth muscle cells and collagen fibres are present between the layers of elastic fibres. Both fibre types are produced by the smooth muscle cells. Each elastic lamella forms together with interlamellar fibres and cells a lamellar unit. The external elastic lamina is difficult to discern from other layers of elastic fibres in the tunica media. The tunica adventitia appears thinner than the tunica media and contains collagen fibres and the cell types typically present in connective tissue.

- The walls of these large arteries are so thick that their peripheral parts cannot derive enough oxygen and nutrients from the blood of the vessel that they form. Larger vessels are therefore accompanied by smaller blood vessels which supply the tunica adventitia and, in the largest vessels, the outer part of the tunica media of the vessel wall. The vessels are called vasa vasorum. In macroscopic preparations vasa vasorum are visible as fine dark lines on the surface of the larger arteries.

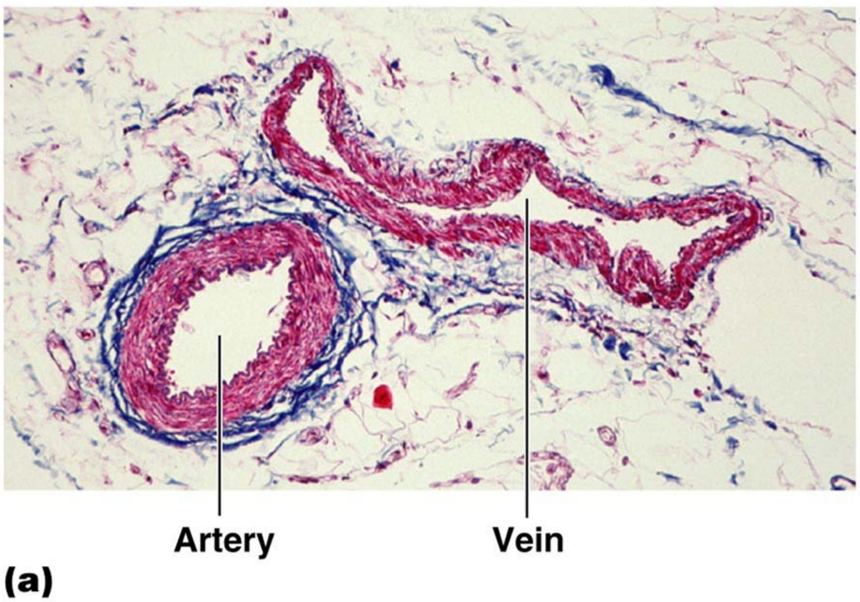

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Figure 19.1a

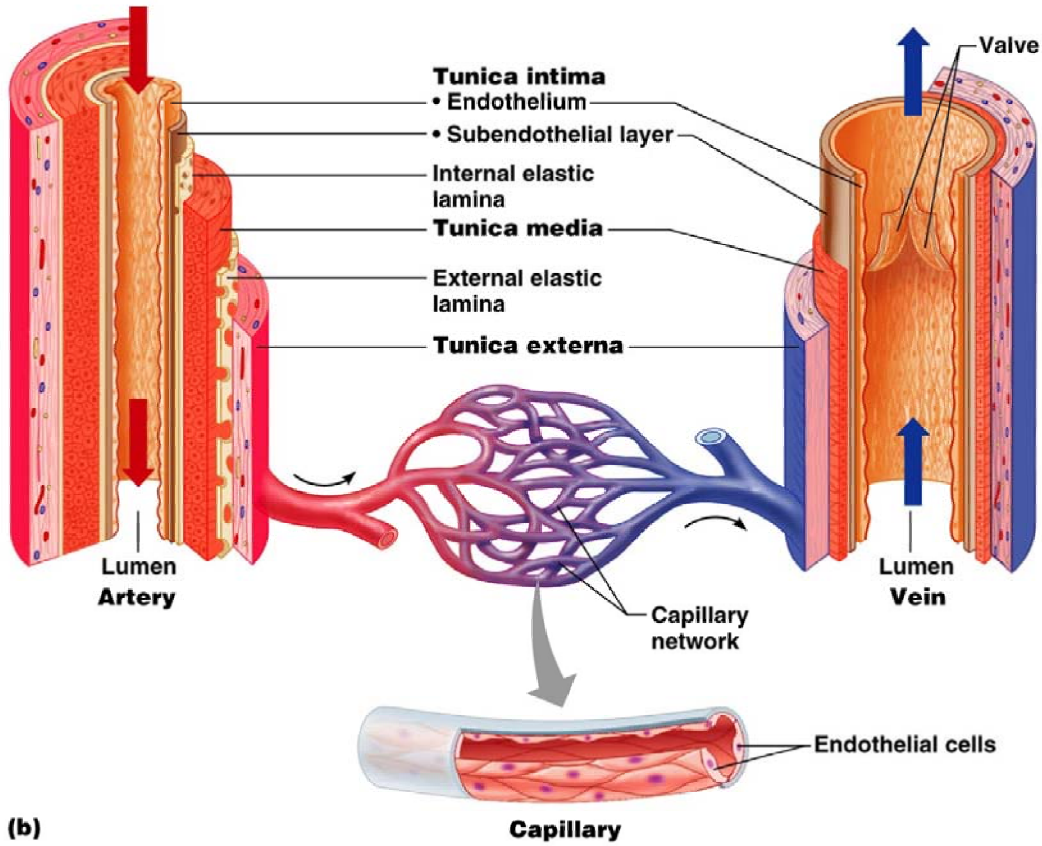

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Figure 19.1b

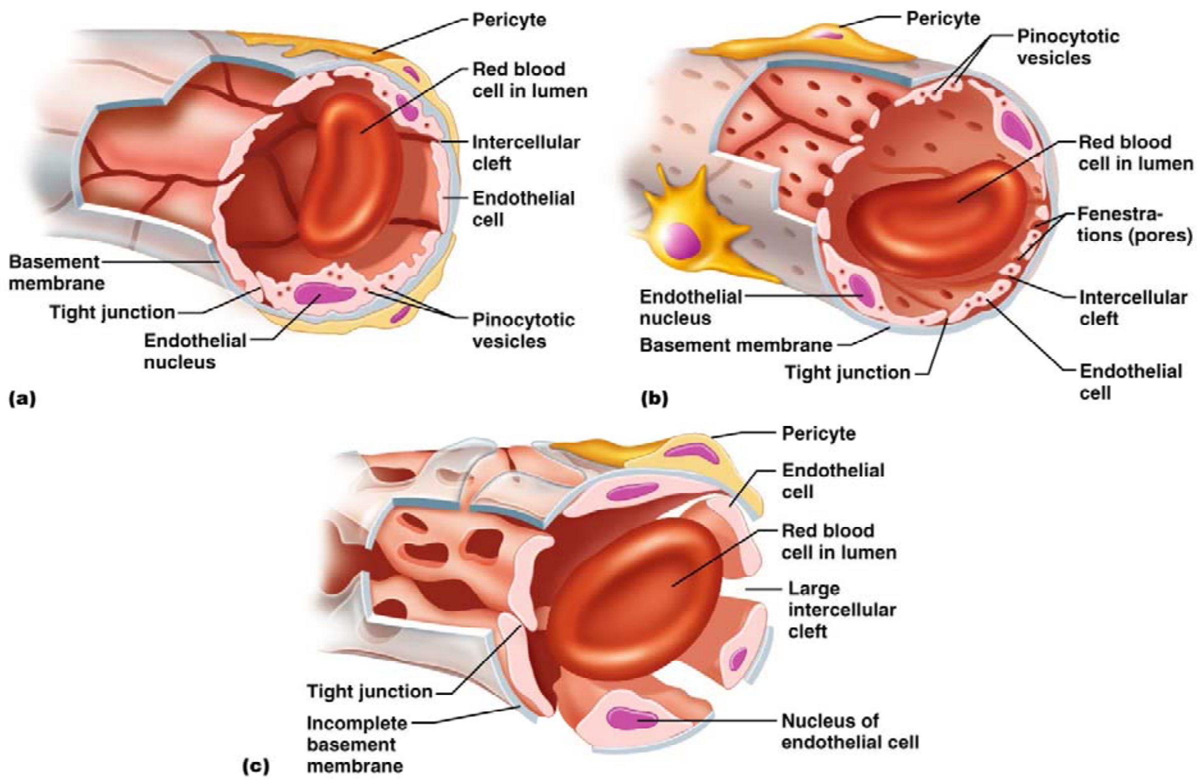

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Figure 19.3

Vascular Components

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

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

Capillaries

The sum of the diameters of all capillaries is significantly larger than that of the aorta (by about three orders of magnitude), which results in decreases in blood pressure and flow rate. Also, capillaries are very small vessels. Their diameter ranges from 4-15 µm. The wall of a segment of capillary may be formed by a single endothelial cell. This results in a very large surface to volume ratio. The low rate of blood flow and large surface area facilitate the functions of capillaries in

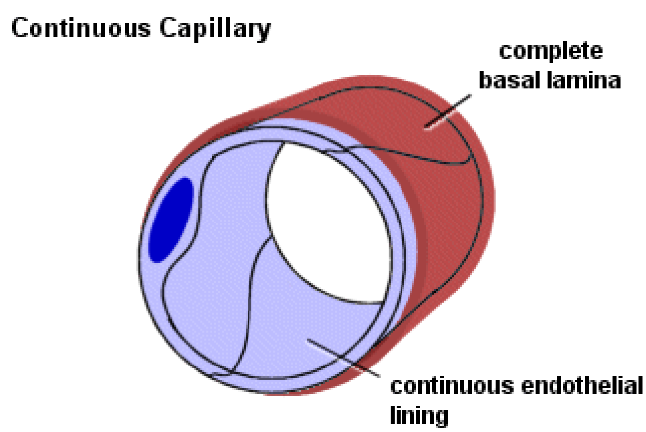
- providing nutrients and oxygen to the surrounding tissue, in
- the absorption of nutrients, waste products and carbon dioxide, and in
- the excretion of waste products from the body.

These functions are also facilitated by a very simple organisation of the wall of capillaries. Only the tunica intima is present, which typically only consists of the endothelium, its basal lamina and an incomplete layer of cells surrounding the capillary, the pericytes . Pericytes have contractile properties and can regulate blood flow in capillaries. In the course of vascular remodelling and repair, they can also differentiate into endothelial and smooth muscle cells.

Three types of capillaries can be distinguished based on features of ethe endothelium.

Continuous capillaries

are formed by "continuous" endothelial cells and basal lamina. The endothelial cell and the basal lamina do not form openings, which would allow substances to pass the capillary wall without passing through both the endothelial cell and the basal lamina.



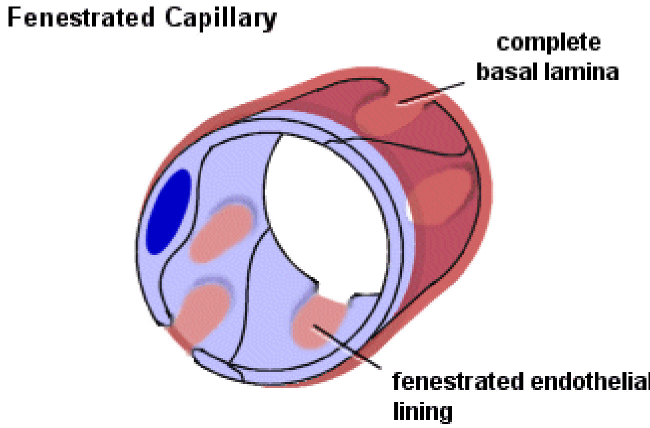
Both endothelial cells and the basal lamina can act as selective filters in continuous capillaries.

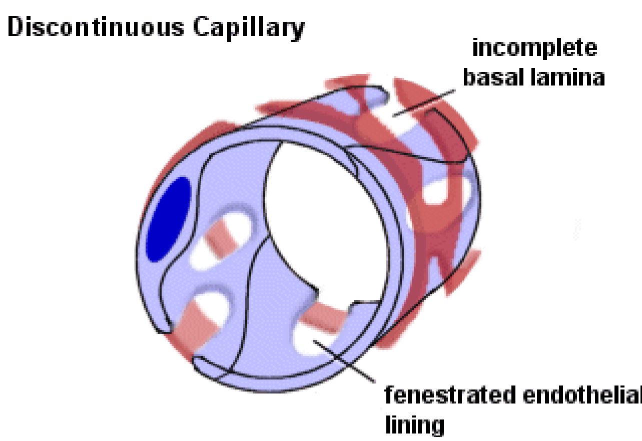
Fenestrated capillaries

The endothelial cell body forms [small] openings called fenestrations, which allow components of the blood and interstitial fluid to bypass the endothelial cells on their way to or from the tissue surrounding the capillary. The fenestrations may represent or arise from pinocytotic vesicles which open onto both the luminal and basal surfaces of the cell. The extent of the fenestration may depend on the physiological state of the surrounding tissue, i.e. fenestration may increase or decrease as a function of the need to absorb or secrete. The endothelial cells are surrounded by a continuous basal lamina, which can act as a selective filter.

Discontinuous capillaries

are formed by fenestrated endothelial cells, which may not even form a complete layer of cells. The basal lamina is also incomplete. Discontinuous capillaries form large irregularly





shaped vessels, sinusoids or sinusoid capillaries. They are found where a very free exchange of substances or even cells between bloodstream and organ is advantageous (e.g. in the liver, spleen, and red bone marrow).

Suitable Slides

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

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)

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)

Vascular Anastomoses

- Merging blood vessels, more common in veins than arteries
- Arterial anastomoses provide alternate pathways (collateral channels) for blood to reach a given body region
  - If one branch is blocked, the collateral channel can supply the area with adequate blood supply
- Thoroughfare channels are examples of arteriovenous anastomoses

Blood Flow

- Actual volume of blood flowing through a vessel, an organ, or the entire circulation in a given period:
  - Is measured in ml per min.
  - Is equivalent to cardiac output (CO), considering the entire vascular system

    - Is relatively constant when at rest
    - Varies widely through individual organs

Blood Pressure (BP)

- Force per unit area exerted on the wall of a blood vessel by its contained blood
    - Expressed in millimeters of mercury (mm Hg)
    - Measured in reference to systemic arterial BP in large arteries near the heart
- The differences in BP within the vascular system provide the driving force that keeps blood moving from higher to lower pressure areas

Resistance

- Resistance – opposition to flow
    - Measure of the amount of friction blood encounters
    - Generally encountered in the systemic circulation
    - Referred to as peripheral resistance (PR)
- The three important sources of resistance are blood viscosity, total blood vessel length, and blood vessel diameter

Resistance Factors: Viscosity and Vessel Length

- Resistance factors that remain relatively constant are:
    - Blood viscosity – "stickiness" of the blood
    - Blood vessel length – the longer the vessel, the greater the resistance encountered

Resistance Factors: Blood Vessel Diameter

- Changes in vessel diameter are frequent and significantly alter peripheral resistance
- Resistance varies inversely with the fourth power of vessel radius
    - For example, if the radius is doubled, the resistance is 1/16 as much
- Small-diameter arterioles are the major determinants of peripheral resistance
- Fatty plaques from atherosclerosis:
    - Cause turbulent blood flow
    - Dramatically increase resistance due to turbulence

Blood Flow, Blood Pressure, and Resistance

- Blood flow (F) is directly proportional to the difference in blood pressure (ΔP) between two points in the circulation
    - If ΔP increases, blood flow speeds up; if ΔP decreases, blood flow declines
- Blood flow is inversely proportional to resistance (R)
    - If R increases, blood flow decreases
- R is more important than ΔP in influencing local blood pressure

Systemic Blood Pressure

- The pumping action of the heart generates blood flow through the vessels along a pressure gradient, always moving from higher- to lower-pressure areas
- Pressure results when flow is opposed by resistance

  Systemic pressure:
    - Is highest in the aorta
    - Declines throughout the length of the pathway

    - Is 0 mm Hg in the right atrium
- The steepest change in blood pressure occurs in the arterioles

Arterial Blood Pressure

- Arterial BP reflects two factors of the arteries close to the heart
    - Their elasticity (compliance or distensibility)
    - The amount of blood forced into them at any given time
- Blood pressure in elastic arteries near the heart is pulsatile (BP rises and falls)
- Systolic pressure – pressure exerted on arterial walls during ventricular contraction
- Diastolic pressure – lowest level of arterial pressure during a ventricular cycle
- Pulse pressure – the difference between systolic and diastolic pressure
- Mean arterial pressure (MAP) – pressure that propels the blood to the tissues
- MAP = diastolic pressure + 1/3 pulse pressure

Capillary Blood Pressure

- Capillary BP ranges from 20 to 40 mm Hg
- Low capillary pressure is desirable because high BP would rupture fragile, thin-walled capillaries
- Low BP is sufficient to force filtrate out into interstitial space and distribute nutrients, gases, and hormones between blood and tissues

Venous Blood Pressure

- Venous BP is steady and changes little during the cardiac cycle
- The pressure gradient in the venous system is only about 20 mm Hg
- A cut vein has even blood flow; a lacerated artery flows in spurts

Factors Aiding Venous Return

- Venous BP alone is too low to promote adequate blood return and is aided by the:
    - Respiratory “pump” – pressure changes created during breathing suck blood toward the heart by squeezing local veins
    - Muscular “pump” – contraction of skeletal muscles “milk” blood toward the heart
- Valves prevent backflow during venous return

Maintaining Blood Pressure

- Maintaining blood pressure requires:
    - Cooperation of the heart, blood vessels, and kidneys
    - Supervision of the brain
- The main factors influencing blood pressure are:
    - Cardiac output (CO)
    - Peripheral resistance (PR)
    - Blood volume
- Blood pressure = CO x PR
- Blood pressure varies directly with CO, PR, and blood volume

Overview of Blood Pressure

***Blood pressure refers to the pressure of blood on the walls of the blood vessels of the body*.**

It is a fundamental principle of Physics that all fluids when held in a container exert a pressure upon the container walls. This pressure is a ***hydrostatic pressure***.

Blood is no exception to this physical principle and therefore blood pressure is a hydrostatic pressure.

Each blood vessel has it's own blood pressure value, arterial blood pressure, capillary blood pressure, venous blood pressure, left atrial blood pressure, right ventricular blood pressure etc.

The pressure in the systemic blood vessels falls continuously from the aorta until the blood re-enters the heart in the right atrium.

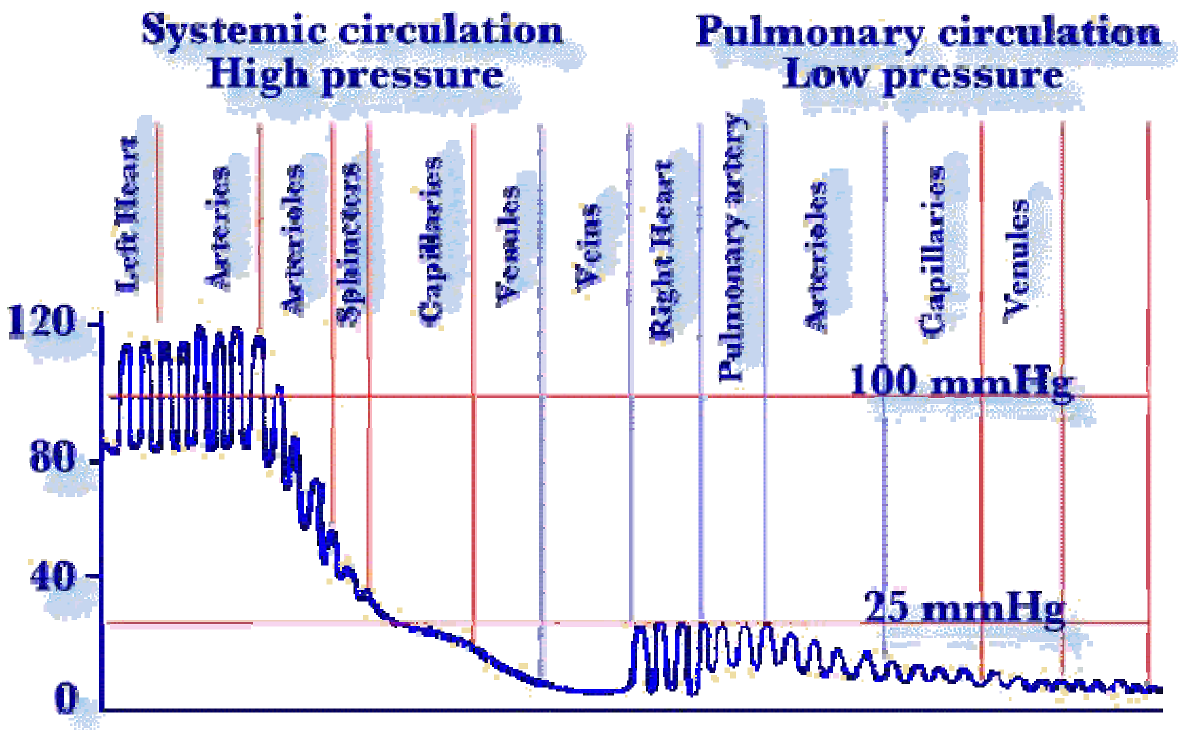


Fig.1 Blood pressure in each section of the systemic and pulmonary circulations

Blood pressure in the pulmonary system is considerably lower than that of the systemic system but there is still a pressure gradient from the blood leaving the right ventricle to the left atrium.

In both systems it is essential to have a pressure gradient so that the blood will flow from the area of highest pressure to the area of lowest pressure thus maintaining the circulation.

In nursing practice reference to blood pressure normally means systemic arterial blood pressure. The use of this as the basic measure is quite appropriate as it is this pressure that ensures an adequate blood flow to the tissues and vital organs. If the pressure falls too far blood flow is reduced, perfusion of the tissues is lowered and shock can occur. Fainting is an example of this, here blood flow to the brain is reduced and loss of consciousness is the result.

There are several mechanisms which exist in order to maintain the blood pressure within normal limits. It is important that the correct blood pressure is maintained if the individual is to maintain a healthy status. As mentioned above low blood pressure leading to shock or fainting.

Abnormal pressure in the blood capillaries can result in abnormal exchange of fluids to and from tissues which can result in conditions such as oedema.

Blood pressure is a function of blood flow and vascular resistance.

As mentioned already, (in the pages on structure and function of blood vessels) the cardiovascular system is a closed system. As a result the total blood flow leaving and entering the heart (in normal health) will be the same. Thus blood flow is equivalent to the **cardiac output**.

Pressure difference is the difference between the mean pressure in the aorta and the pressure in the vena cava just before the blood enters the heart (this latter value is almost zero). Since the blood pressure is essentially the same in the aorta and all large arteries, the pressure difference can be said to be equivalent to mean arterial pressure.

Resistance to flow is the total resistance to blood flow. As the majority of the resistance is found in the peripheral vessels, especially the arterioles, it is often described as the total peripheral resistance.

Thus we have the equation

Blood Pressure = Cardiac Output x Total Peripheral Resistance

or

BP = CO x TPR

This is one of the fundamental equations of cardiovascular physiology. You can see from the equation that blood pressure can be maintained by altering cardiac output and/or total peripheral resistance. The cardiac output itself is changed by altering the heart rate and stroke volume.

Arterial blood pressure fluctuates throughout the cardiac cycle. The contraction of the ventricles ejects blood into the pulmonary and systemic arteries during systole and this additional volume of blood distends the arteries and raises the arterial pressure. When the contraction ends, the stretched elastic arterial walls recoil passively and this continues to drive blood through the arterioles. As the blood leaves the arteries the pressure falls; the arterial pressure never falls to zero because the next ventricular contraction occurs whilst there is still an appreciable amount of blood within the arteries. Thus the pressure in the major arteries rises and falls as the heart contracts and relaxes. The maximum pressure occurs after ventricular systole and is known as the **systolic pressure**. When the blood pressure in the aorta exceeds that in the ventricle, the aortic valve closes; this accounts for the **dicrotic notch**.

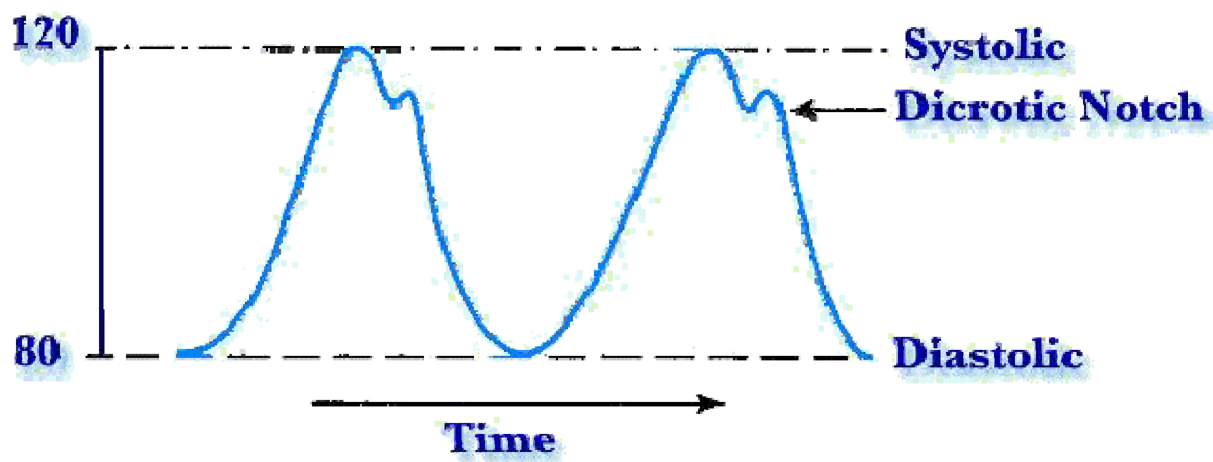
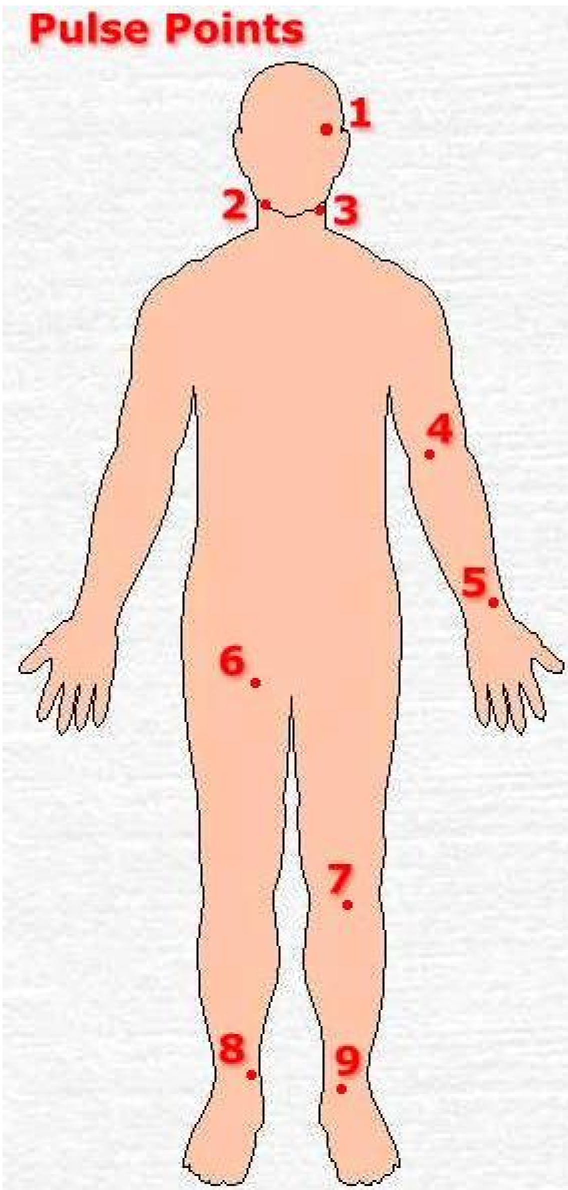


Fig 2. Wave form showing variation in blood pressure in the main arteries as the heart contracts and relaxes.

Once the aortic valve has closed, the blood pressure in the aorta and large arteries falls as blood flows through the arterioles and capillaries to the veins. The level to which the arterial pressure has fallen before the next ventricular systole, that is the minimum pressure, is known as the diastolic pressure.

The systolic pressure is determined by the amount of blood being forced into the aorta and arteries with each ventricular contraction, i.e. the stroke volume, and also by the force of contraction. An increase in either will increase the systolic pressure. Similarly, if the arterial wall becomes stiffer, as happens in arteriosclerosis, the vessels are not able to distend with the increased blood volume and so the systolic pressure is increased.

Diastolic pressure is also influenced by several factors. The diastolic pressure provides information on the degree of peripheral resistance: if there is increased arteriolar vasoconstriction, this will impede blood flowing out of the arterial system to the capillaries, and the diastolic pressure will rise. Conversely, if the peripheral resistance is reduced by vasodilation, more blood will flow out of the arterial system and thus diastolic pressure will fall. Drugs that modify the degree of arterial vasoconstriction and alter the peripheral resistance will obviously affect the diastolic pressure, and vasodilator drugs, for example hydralazine hydrochloride (Apresoline), minoxidil (Loniten), are sometimes used in the treatment of severe hypertension.



The diastolic pressure also depends on the level of the systolic pressure, the elasticity of the arteries and the viscosity of the blood. Alterations in the heart rate will also affect diastolic pressure: with a slower heart rate, the diastolic pressure will be lower as there is a greater time for blood to flow out of the arteries, and vice versa.

PULSE PRESSURE AND MEAN ARTERIAL PRESSURE. Each ventricular contraction initiates a pulse, or wave, of pressure through the arteries and these pulses can be palpated (felt) wherever an artery passes near the skin and over a bony or firm surface.

Figure. 3 to the left shows the common sites where the pulse is felt.

1. Temporal artery at the temple above and to the outer side of the eye

2. External maxillary (facial) artery at the point of crossing the mandible (lower jaw)

3. Carotid artery on the side of the neck

4. Brachial artery on the inner side of the biceps

5. Radial artery on the radial bone side

of the wrist

6. Femoral artery in the groin

7. Popliteal artery behind the knee

8. Posterior tibial pulse behind the inner ankle

9. Dorsalis pedis artery on the upper front part (anteriosuperior aspect) of the foot

There is one pulse per heart beat, and so the pulse rate is used as an easy method for counting the heart rate. These palpable pulses represent the difference between the systolic and diastolic pressures and this difference is known as the pulse pressure, e.g. the pulse pressure in an individual whose blood pressure is 130/80 mmHg is

(130-80) = 50 mmHg.

Two of the main factors that alter the pulse pressure are the stroke volume and decreased arterial compliance.

It is sometimes useful to have an average, or mean, value for the arterial pressure, rather than maximum and minimum (systolic and diastolic) pressures, as it is the mean pressure that represents the pressure driving blood through the systemic circulation.

The mean arterial pressure is not a simple arithmetical mean; it is estimated by adding one-third of the pulse pressure to the diastolic pressure. So, for a blood pressure of 130/80 mmHg

mean arterial pressure is

80 + (1/3 x 50) = 96.67 mmHg

From the point of view of actual tissue perfusion, it is generally the mean arterial pressure that matters, rather than the precise values of systolic and diastolic pressures.

Blood pressure values. There is no such value as a 'normal' blood pressure for the population as a whole; there is a usual or 'normal' value for any particular individual, but even that value varies from moment to moment under different circumstances and over longer periods of time. Many factors, both physiological and genetic, have an influence on blood pressure and thus it is not surprising that individuals have significantly different, but 'normal', blood pressure values. Therefore it is more appropriate to refer to a normal range of blood pressure than to a single value.

Normal blood pressures are said to range from 100/60 mmHg to 150/90 mmHg.

Age (years)	Systolic pressure	Diastolic pressure

	(mmHg)	(mmHg)
New-born	80	46
10	103	70
20	120	80
40	126	84
60	135	89

Table 1. Some 'average' blood pressures relating to age

Parameters such as age, sex, and race influence blood pressure values. In Western societies, blood pressure values tend to increase with advancing age therefore a blood pressure which would be 'normal' for a 70 year old might be considered 'abnormal' for a 40 year old. This is not universal, for example South Pacific Islanders show little, if any, increase in mean blood pressure with increasing age . The elevation in blood pressure with age may be due either to genetic or environmental factors and is likely to be a result of arteriosclerosis.

Men generally have higher blood pressures than women. Race also seems to influence blood pressure levels, e.g. in the USA Afro-Caribbean races tend to have higher blood pressures than whites.

Most authorities agree that a resting diastolic pressure persistently exceeding 90 mmHg or 95 mmHg indicates hypertension, that is, a raised blood pressure; this is an arbitrary definition but proves to be useful for clinical practice. A persistently low blood pressure, hypotension, is relatively rare, although temporary or transient hypotension is more common, e.g. in haemorrhage or fainting.

HYPERTENSION. One of the reasons that clinicians are so concerned about the level of an individual's blood pressure is that there is a significantly increased mortality in those with untreated hypertension when compared with individuals with a 'normal' blood pressure (normotensive): a 35-year-old man with a diastolic pressure of 100 mmHg can expect a 16-year reduction in life expectancy.

It has been estimated that nearly one-quarter of the adult population in the UK has an elevated blood pressure.

Individuals who are hypertensive usually have few, if any, symptoms and often the hypertension is only diagnosed as part of a routine medical screening, for example for insurance purposes. The effects of a raised blood pressure are insidious and develop over many years: the heart has to increase in size (detectable on x-ray) and strength to overcome the increased resistance caused by the increased blood pressure.

The arteries respond to the increased pressure by hypertrophy of the smooth muscle in their walls, so that they are able to withstand exposure to the higher pressures.

Atherosclerosis formation is also potentiated. The blood vessels most commonly affected are the cerebral, coronary and renal vessels; cerebrovascular accidents (strokes) and myocardial infarctions are the commonest clinical manifestations, followed by renal disease.

There has been much research and discussion into the causes of hypertension. In a few instances, hypertension is secondary to renal or endocrine disease, but in the majority of cases the cause of primary or essential hypertension is not fully understood.

The aetiology of essential hypertension is almost certainly multifactorial and it is likely to prove to be a combination of genetic and environmental factors. Mechanisms that seem to be involved include some that affect the extracellular fluid volume and expand the circulating blood volume, e.g. excessive renin secretion and angiotensin production, increased sympathetic activity and excessive dietary salt intake, possibly associated with a low potassium intake.

Some of the treatments prescribed for hypertension relate to these mechanisms, i.e. diuretics (e.g. a thiazide) to increase sodium and water loss; methyldopa, B-adrenoreceptor blocking drugs (e.g. propranolol), and relaxation techniques to reduce sympathetic activity; restriction of salt intake. One drug, captopril, inhibits angiotensin converting enzyme in the lungs and reduces the production of angiotensin II.

Raised peripheral resistance is linked with hypertension and so drugs that produce vasodilation are useful.

There are many risk factors associated with the development of hypertension, including obesity, high alcohol and salt intakes and some drugs (e.g. oral contraceptives, corticosteroids, monoamine oxidase inhibitors). There is also often a positive family history of hypertension: if both parents are hypertensive, there is a significantly greater risk that their children will also develop high blood pressure.

If hypertension is diagnosed and effectively treated, usually by drug therapy, much of the cardiovascular-related disease can be prevented.

Measurement of arterial blood pressure. The first documented measurement of blood pressure dates back to the eighteenth century. In 1773, Stephen Hales, an English theologian and scientist, directly measured mean blood pressure in an unanaesthetized horse by inserting an open-ended tube directly into the animal's neck.

The blood entered the tube and rose upwards (to a height of 2.5 m) towards the tube opening until the weight of the column of blood was equal to the pressure in the circulatory system of the horse. This is the basis of a simple pressure manometer which is still used for measuring blood pressure. It is the basis too for measuring cerebrospinal fluid pressures during a lumbar puncture.

Catheters can be inserted directly into an artery (the radial artery is often used) to give direct arterial pressure measurements. The indwelling catheter is now usually attached to small electronic transducers, and pressures can be monitored continuously.

However, in most instances it is not desirable or practicable to use invasive techniques to measure arterial pressures. In the eighteenth century, an Italian physiologist, Scipione Riva Rocci, invented the sphygmomanometer (sphygmo = pulse and manometer = pressure meter hence the meaning is "pulse pressure meter") which enabled a non-invasive measurement of systolic pressure.

A rubber inflatable cuff is placed over the brachial artery and the pressure in the cuff is raised until the cuff pressure exceeds that of the blood in the artery.

At this point the artery collapses and no radial pulse can be felt as blood is not able to flow through the brachial artery. The pressure in the cuff is then slowly released and the radial pulse reappears. The pressure at which the pulse reappears corresponds to the systolic pressure as it is the point at which the peak pressure (i.e. the systolic) in the brachial artery exceeds the occluding pressure in the cuff.

The mercury sphygmomanometer is used as the standard reference for measuring blood pressure and it still forms the basis for our present-day indirect method of assessing arterial pressure although it is now somewhat more sophisticated and uses electronic output.

Traditionally, blood pressure is measured in millimetres of mercury (written as mmHg); this means that if the blood pressure is 100 mmHg, the pressure exerted by the blood is sufficient to push a column of mercury up to a height of 100 mm. (The SI unit for pressure is the Pascal (Pa) or kilopascal (kPa) and so sometimes blood pressure may be written as, say, 13.3kPa instead of 100 mmHg.)

The method was developed further a few years after Riva Rocci by a Russian surgeon, Dr Nicolai Korotkov. Korotkov reported a method for measuring both systolic and diastolic pressures by auscultation, that is, by listening, using a stethoscope placed over the brachial artery and the sphygmomanometer. Various sounds were audible and Korotkov classified the sounds into five phases, which are now known simply as the Korotkov sounds.

Phase	Sound	Approx. Pressure in mmHg
1	Sharp, clear	120-110
2	Blowing or swishing	109-100
3	Sharp but softer than in 1	99-88
4	Muffled, fading	82-87

5	No sound	< 81

Table 2 Korotkov sounds

The precise origin of the various Korotkov sounds is not fully understood, but they are due primarily to turbulent flow and vibratory phenomena in the brachial artery as it opens and closes with each beat and as the blood flows through the semi-occluded vessel. When the pressure in the blood pressure cuff is greater than that in the artery, the vessel is completely occluded and there is no blood flow and no turbulence, and hence no sound.

There is considerable controversy as to whether phase 4, the muffling of the sounds, or phase 5, the disappearance of the sounds, is the best measure of the diastolic pressure. In the UK, phase 4 is favoured in clinical practice, whereas in the USA, phase 5 is used.

Some researchers suggest that both phases 4 and 5 should be recorded, for example 120/72/64 mmHg. Phase 5 correlates better with direct arterial measurement of blood pressure and there is also often better agreement among observers when using the disappearance of sounds rather than muffling. The main problem with using phase 5 is that in some individuals, especially when the cardiac output is high, the sounds do not disappear (although they do muffle), and sometimes persist right down to zero. However, in most people muffling and disappearance of the sounds usually occur within 10 mmHg of each other and may even occur together. When transferring between hospitals, nurses should always check on local policy regarding this.

Of course we now have electronic sphygmomanometers which remove some of this ambiguity, however the ausculatory method is still a valuable nursing skill.

Nurses should ensure that blood pressure measurements are taken under standardised conditions and using the correct technique. Blood pressure values vary according to the situation that the individual is in and many physiological variables influence them. The individual should rest for at least 5 minutes before measurement, and should avoid exertion and not eat or smoke for 30 minutes beforehand. Both systolic and diastolic pressures are reported to rise by 10-33 mmHg within 15-45 minutes after the subject has eaten a meal. Blood pressure also rises as the bladder fills.

The emotional state of the patient, e.g. whether anxious or in pain, will affect blood pressure values, but this is often difficult to avoid in clinical situations. The simple arrival of doctors at the bedside of patients can induce an immediate rise in blood pressure (and heart rate), with mean values increasing by approximately 27 mmHg for systolic and 15 mmHg for diastolic above the pre visit values. The fact that anxiety influences blood pressure readings should be remembered, especially when intending to use observations taken at the time of admission to hospital as a baseline for subsequent observations.

There are also many potential sources for error in the actual measurement technique, for instance, the arm should be at heart level or, more specifically, the arm should be horizontal with the fourth intercostal space at the sternum. The observer should also support the patient's arm, otherwise the patient will have to perform isometric muscle contractions which can increase the diastolic pressure. Raising or lowering the arm away from heart level causes significant changes in blood pressures, the error can be as large as 10 mmHg. The same arm should be used each time as in some individuals there are differences in the right and left brachial artery pressures. An appropriate size cuff should also be used; ideally the bladder of the cuff should encircle the arm, but if this is not feasible the centre of the bladder must be placed directly over the brachial artery. Tight or constricting sleeves of clothes pushed up to allow application of the cuff will also give false readings.

Observer bias, especially by looking at previously charted values and expectations of individuals' values, e.g. older people having higher blood pressures, is also a potential source of inaccuracy. The observer should also be at eye level with the mercury manometer scale when reading off the values. For some reason observers show a strong preference for the terminal digits 0 and 5, e.g. 125/75 mmHg, even though a 5-mmHg mark does not appear on many scales!

It is advisable to record an approximate value for systolic pressure by palpation, before auscultation, because in some people the Korotkov sounds appear normally giving the systolic pressure, but then disappear for a short time before returning above the diastolic pressure. This period of silence is known as the auscultatory gap and, although nothing can be heard, the pulse can be felt.

On many occasions it may not be possible to obtain all the optimum conditions, and if this is the case the qualifying factor(s) should be recorded on the chart, e.g. '150/94 mmHg - patient in severe pain'.

Figure 4. Factors influencing accuracy of sphygmomanometer reading

Sphygmomanometer: Height, Upright scale, maintenance, clogged vent, level of mercury

Nurse: Training, Observer Bias, Preferred digit, Lack of concentration, Sight, Hearing, Distance from sphygmomanometer, Diastolic dilemma

Cuff: Correct application, Dimensions of bladder, Positioning of bladder.

State of patient: Anxiety, Pain, Fear, Recent exercise, Full bladder, Food, Tobacco, Alcohol, Obesity, Arrhytmias.

Patient: Position, Right Arm, Left Arm, Support to arm.

Environment: Temperature, Noise, Distractions

If it is not possible to use the arms for blood pressure readings, it is possible, using special large leg cuffs, to record the blood pressure using the Korotkov sounds from the popliteal artery in the popliteal fossa (at the back of the knee). The technique is more cumbersome but is useful in some instances, e.g. for patients with suspected coarctation of the aorta or with arm injuries. Pressure in the arteries of the legs is normally the same as that in the arms.

Aneroid sphygmomanometers that work on a bellows system rather than on a mercury column, and also semiautomated systems that detect Korotkov sounds using a microphone or detect arterial blood flow using ultrasound, may be used clinically to measure blood pressure. However, the values obtained do not exactly correlate with direct arterial measurements.

A crude value for mean arterial pressure can be obtained using the method described earlier to demonstrate reactive hyperaemia. The mean arterial pressure is the pressure level when the arm flushes bright red as blood returns to the arm. This is described as the 'flush method' and is sometimes used in children or in shocked patients when other methods are not possible.

Cardiac Output (CO)

- Cardiac output is determined by venous return and neural and hormonal controls
- Resting heart rate is controlled by the cardioinhibitory center via the vagus nerves
    - Stroke volume is controlled by venous return (end diastolic volume, or EDV)
- Under stress, the cardioacceleratory center increases heart rate and stroke volume
    - The end systolic volume (ESV) decreases and MAP increases

Controls of Blood Pressure

- Short-term controls:
    - Are mediated by the nervous system and bloodborne chemicals
    - Counteract moment-to-moment fluctuations in blood pressure by altering peripheral resistance
- Long-term controls regulate blood volume

Short-Term Mechanisms: Neural Controls

- Neural controls of peripheral resistance:
    - Alter blood distribution in response to demands
    - Maintain MAP by altering blood vessel diameter
- Neural controls operate via reflex arcs involving:
    - Baroreceptors
    - Vasomotor centers and vasomotor fibers
    - Vascular smooth muscle

Short-Term Mechanisms: Vasomotor Center

- Vasomotor center – a cluster of sympathetic neurons in the medulla that oversees changes in blood vessel diameter
    - Maintains blood vessel tone by innervating smooth muscles of blood vessels, especially arterioles
- Cardiovascular center – vasomotor center plus the cardiac centers that integrate blood pressure control by altering cardiac output and blood vessel diameter

Short-Term Mechanisms: Vasomotor Activity

- Sympathetic activity causes:
    - Vasoconstriction and a rise in BP if increased
    - BP to decline to basal levels if decreased
- Vasomotor activity is modified by:

   - Baroreceptors (pressure-sensitive), chemoreceptors (O_2, CO_2, and H^+ sensitive), higher brain centers, bloodborne chemicals, and hormones

Short-Term Mechanisms: Baroreceptor-Initiated Reflexes
- Increased blood pressure stimulates the cardioinhibitory center to:
   - Increase vessel diameter
   - Decrease heart rate, cardiac output, peripheral resistance, and blood pressure
- Declining blood pressure stimulates the cardioacceleratory center to:
   - Increase cardiac output and peripheral resistance
- Low blood pressure also stimulates the vasomotor center to constrict blood vessels

Short-Term Mechanisms: Chemical Controls
- Blood pressure is regulated by chemoreceptor reflexes sensitive to oxygen and carbon dioxide
   - Prominent chemoreceptors are the carotid and aortic bodies
   - Reflexes that regulate BP are integrated in the medulla
   - Higher brain centers (cortex and hypothalamus) can modify BP via relays to medullary centers

Chemicals that Increase Blood Pressure
- ***Adrenal medulla hormones – norepinephrine and epinephrine increase blood pressure***
- ***Antidiuretic hormone (ADH) – causes intense vasoconstriction in cases of extremely low BP***
- ***Angiotensin II – kidney release of renin generates angiotensin II, which causes vasoconstriction***
- ***Endothelium-derived factors – endothelin and prostaglandin-derived growth factor (PDGF) are both vasoconstrictors***

Chemicals that Decrease Blood Pressure
- Atrial natriuretic peptide (ANP) – causes blood volume and pressure to decline
- Nitric oxide (NO) – is a brief but potent vasodilator
- Inflammatory chemicals – histamine, prostacyclin, and kinins are potent vasodilators
- Alcohol – causes BP to drop by inhibiting ADH

Long-Term Mechanisms: Renal Regulation
- Long-term mechanisms control BP by altering blood volume
- Baroreceptors adapt to chronic high or low BP
   - Increased BP stimulates the kidneys to eliminate water, thus reducing BP
   - Decreased BP stimulates the kidneys to increase blood volume and BP

Kidney Action and Blood Pressure
- Kidneys act directly and indirectly to maintain long-term blood pressure
   - Direct renal mechanism alters blood volume
   - Indirect renal mechanism involves the renin-angiotensin mechanism
   - Declining BP causes the release of renin, which triggers the release of angiotensin II
   - Angiotensin II is a potent vasoconstrictor that stimulates aldosterone secretion
   - Aldosterone enhances renal reabsorption and stimulates ADH release

Monitoring Circulatory Efficiency
- Efficiency of the circulation can be assessed by taking pulse and blood pressure measurements
- Vital signs – pulse and blood pressure, along with respiratory rate and body temperature
- Pulse – pressure wave caused by the expansion and recoil of elastic arteries
   - Radial pulse (taken on the radial artery at the wrist) is routinely used

  - Varies with health, body position, and activity

Measuring Blood Pressure
- Systemic arterial BP is measured indirectly with the auscultatory method
  - A sphygmomanometer is placed on the arm superior to the elbow
  - Pressure is increased in the cuff until it is greater than systolic pressure in the brachial artery
  - Pressure is released slowly and the examiner listens with a stethoscope
  - The first sound heard is recorded as the systolic pressure
  - The pressure when sound disappears is recorded as the diastolic pressure

Variations in Blood Pressure
- Blood pressure cycles over a 24-hour period
- BP peaks in the morning due to waxing and waning levels of retinoic acid
- Extrinsic factors such as age, sex, weight, race, mood, posture, socioeconomic status, and physical activity may also cause BP to vary

Alterations in Blood Pressure
- Hypotension – low BP in which systolic pressure is below 100 mm Hg
- Hypertension – condition of sustained elevated arterial pressure of 140/90 or higher
  - Transient elevations are normal and can be caused by fever, physical exertion, and emotional upset
  - Chronic elevation is a major cause of heart failure, vascular disease, renal failure, and stroke

Hypotension
- Orthostatic hypotension – temporary low BP and dizziness when suddenly rising from a sitting or reclining position
- Chronic hypotension – hint of poor nutrition and warning sign for Addison's disease
- Acute hypotension – important sign of circulatory shock
  - Threat to patients undergoing surgery and those in intensive care units

Hypertension
- Hypertension maybe transient or persistent
- Primary or essential hypertension – risk factors in primary hypertension include diet, obesity, age, race, heredity, stress, and smoking
- Secondary hypertension – due to identifiable disorders, including excessive renin secretion, arteriosclerosis, and endocrine disorders

Blood Flow Through Tissues
- Blood flow, or tissue perfusion, is involved in:
  - Delivery of oxygen and nutrients to, and removal of wastes from, tissue cells
  - Gas exchange in the lungs
  - Absorption of nutrients from the digestive tract
  - Urine formation by the kidneys
- Blood flow is precisely the right amount to provide proper tissue function

Velocity of Blood Flow
- Blood velocity:
  - Changes as it travels through the systemic circulation
  - Is inversely proportional to the cross-sectional area
- Slow capillary flow allows adequate time for exchange between blood and tissues

Autoregulation: Local Regulation of Blood Flow
- Autoregulation – automatic adjustment of blood flow to each tissue in proportion to its requirements at any given point in time
- Blood flow through an individual organ is intrinsically controlled by modifying the diameter of local

arterioles feeding its capillaries
- MAP remains constant, while local demands regulate the amount of blood delivered to various areas according to need

Metabolic Controls
- Declining tissue nutrient and oxygen levels are stimuli for autoregulation
- Hemoglobin delivers nitric oxide (NO) as well as oxygen to tissues
- Nitric oxide induces vasodilation at the capillaries to help get oxygen to tissue cells
- Other autoregulatory substances include: potassium and hydrogen ions, adenosine, lactic acid, histamines, kinins, and prostaglandins

Myogenic Controls
- Inadequate blood perfusion or excessively high arterial pressure:
  - Are autoregulatory
  - Provoke myogenic responses – stimulation of vascular smooth muscle
- Vascular muscle responds directly to:
  - Increased vascular pressure with increased tone, which causes vasoconstriction
  - Reduced stretch with vasodilation, which promotes increased blood flow to the tissue

Long-Term Autoregulation
- Is evoked when short-term autoregulation cannot meet tissue nutrient requirements
- May evolve over weeks or months to enrich local blood flow
- 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

Blood Flow: Skeletal Muscles
- Resting muscle blood flow is regulated by myogenic and general neural mechanisms in response to oxygen and carbon dioxide levels
- When muscles become active, hyperemia is directly proportional to greater metabolic activity of the muscle (active or exercise hyperemia)
- Arterioles in muscles have cholinergic, and alpha (α) and beta (β) adrenergic receptors
- α and β adrenergic receptors bind to epinephrine

Blood Flow: Skeletal Muscle Regulation
- Muscle blood flow can increase tenfold or more during physical activity as vasodilation occurs
  - Low levels of epinephrine bind to β receptors
  - Cholinergic receptors are occupied
- Intense exercise or sympathetic nervous system activation results in high levels of epinephrine
  - High levels of epinephrine bind to α receptors and cause vasoconstriction
    - This is a protective response to prevent muscle oxygen demands from exceeding cardiac pumping ability

Blood Flow: Brain
- Blood flow to the brain is constant, as neurons are intolerant of ischemia
- Metabolic controls – brain tissue is extremely sensitive to declines in pH, and increased carbon dioxide causes marked vasodilation
- Myogenic controls protect the brain from damaging changes in blood pressure
  - Decreases in MAP cause cerebral vessels to dilate to ensure adequate perfusion
  - Increases in MAP cause cerebral vessels to constrict
- The brain can regulate its own blood flow in certain circumstances, such as ischemia caused by a tumor
- The brain is vulnerable under extreme systemic pressure changes

- MAP below 60mm Hg can cause syncope (fainting)
- MAP above 160 can result in cerebral edema

Blood Flow: Skin

- Blood flow through the skin:
  - Supplies nutrients to cells in response to oxygen need
  - Helps maintain body temperature
  - Provides a blood reservoir
- Blood flow to venous plexuses below the skin surface:
  - Varies from 50 ml/min to 2500 ml/min, depending on body temperature
  - Is controlled by sympathetic nervous system reflexes initiated by temperature receptors and the central nervous system

Temperature Regulation

- As temperature rises (e.g., heat exposure, fever, vigorous exercise):
  - Hypothalamic signals reduce vasomotor stimulation of the skin vessels
  - Heat radiates from the skin
- Sweat also causes vasodilation via bradykinin in perspiration
  - Bradykinin stimulates the release of NO
- As temperature decreases, blood is shunted to deeper, more vital organs

Blood Flow: Lungs

- Blood flow in the pulmonary circulation is unusual in that:
  - The pathway is short
  - Arteries/arterioles are more like veins/venules (thin-walled, with large lumens)
  - They have a much lower arterial pressure (24/8 mm Hg versus 120/80 mm Hg)
  - The autoregulatory mechanism is exactly opposite of that in most tissues
    - Low oxygen levels cause vasoconstriction; high levels promote vasodilation
    - This allows for proper oxygen loading in the lungs

Blood Flow: Heart

- Small vessel coronary circulation is influenced by:
  - Aortic pressure
  - The pumping activity of the ventricles
- During ventricular systole:
  - Coronary vessels compress
  - Myocardial blood flow ceases
  - Stored myoglobin supplies sufficient oxygen
- During ventricular diastole, oxygen and nutrients are carried to the heart
- Under resting conditions, blood flow through the heart may be controlled by a myogenic mechanism
- During strenuous exercise:
  - Coronary vessels dilate in response to local accumulation of carbon dioxide
  - Blood flow may increase three to four times
  - Blood flow remains constant despite wide variation in coronary perfusion pressure

Capillary Exchange of Respiratory Gases and Nutrients

- Oxygen, carbon dioxide, nutrients, and metabolic wastes diffuse between the blood and interstitial fluid along concentration gradients
  - Oxygen and nutrients pass from the blood to tissues
  - Carbon dioxide and metabolic wastes pass from tissues to the blood
  - Water-soluble solutes pass through clefts and fenestrations
  - Lipid-soluble molecules diffuse directly through endothelial membranes

Capillary Exchange: Fluid Movements

- Direction and amount of fluid flow depends upon the difference between:
  - Capillary hydrostatic pressure (HP_c)

- Capillary colloid osmotic pressure (OP_c)
- HP_c – pressure of blood against the capillary walls:
  - Tends to force fluids through the capillary walls
  - Is greater at the arterial end of a bed than at the venule end
- OP_c– created by nondiffusible plasma proteins, which draw water toward themselves

Net Filtration Pressure (NFP)
- NFP – all the forces acting on a capillary bed
- $NFP = (HP_c – HP_{if}) – (OP_c – OP_{if})$
- At the arterial end of a bed, hydrostatic forces dominate (fluids flow out)
- At the venous end of a bed, osmotic forces dominate (fluids flow in)
- More fluids enter the tissue beds than return blood, and the excess fluid is returned to the blood via the lymphatic system

Circulatory Shock
- Circulatory shock – any condition in which blood vessels are inadequately filled and blood cannot circulate normally
- Results in inadequate blood flow to meet tissue needs
- Three types include:
  - Hypovolemic shock – results from large-scale blood loss
  - Vascular shock – poor circulation resulting from extreme vasodilation
  - Cardiogenic shock – the heart cannot sustain adequate circulation

Circulatory Pathways
- The vascular system has two distinct circulations
  - Pulmonary circulation – short loop that runs from the heart to the lungs and back to the heart
  - Systemic circulation – routes blood through a long loop to all parts of the body and returns to the heart

Developmental Aspects
- The endothelial lining of blood vessels arises from mesodermal cells, which collect in blood islands
  - Blood islands form rudimentary vascular tubes through which the heart pumps blood by the fourth week of development
- Fetal shunts (foramen ovale and ductus arteriosus) bypass nonfunctional lungs
- The ductus venosus bypasses the liver
- The umbilical vein and arteries circulate blood to and from the placenta
- Blood vessels are trouble-free during youth
- Vessel formation occurs:
  - As needed to support body growth
  - For wound healing
  - To rebuild vessels lost during menstrual cycles
- With aging, varicose veins, atherosclerosis, and increased blood pressure may arise