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**QUESTIONS**

1. Discuss the long-term regulation of mean arterial blood pressure?
2. Write short notes on the following:
    a) Pulmonary circulation
    b) Circle of Willis
    c) Splanchnic circulation
    d) Coronary circulation
    e) Cutaneous circulation
3. Discuss the cardiovascular adjustment that occurs during exercise?

# Long-Term Regulation of Mean Arterial Blood Pressure

**Mean arterial pressure (MAP)** is the average arterial blood pressure in an individual during one cardiac cycle, systole, and diastole.

Mean arterial blood pressure is the average pressure existing in the arteries.
It is not the arithmetic mean of systolic and diastolic pressures. It is the diastolic pressure plus one third of pulse pressure. To determine the mean pressure, diastolic pressure is considered than the systolic pressure. It is because; the diastolic period of cardiac cycle is longer (0.53 second) than the systolic period (0.27 second).
*Normal mean arterial pressure:* 93 mm Hg (80 + 13= 93).

## Formula to calculate mean arterial blood pressure:

Mean arterial blood pressure
= Diastolic pressure + 1/3 of pulse pressure
= 80 + 40/3 = 93.3 mm Hg

## Renal Mechanism for Regulation of Blood Pressure–Long-Term Regulation

Kidneys play an important role in the long-term regulation of arterial blood pressure. When blood pressure alters slowly in several days/months/years, the nervous mechanism adapts to the altered pressure and looses the sensitivity for the changes. It cannot regulate the pressure any more. In such conditions, the renal mechanism operates efficiently to regulate the blood pressure. Therefore, it is called long-term regulation. Kidneys regulate arterial blood pressure by two ways:

1. By regulation of ECF volume
2. Through renin-angiotensin mechanism.

## By Regulation of Extracellular Fluid Volume

When the blood pressure increases, kidneys excrete large amounts of water and salt, particularly sodium, by means of **pressure diuresis** and pressure natriuresis. Pressure diuresis is the excretion of large quantity of water in urine because of increased blood pressure. Even a slight increase in blood pressure doubles the water excretion. Pressure natriuresis is the excretion of large quantity of sodium in urine. Because of **diuresis** and **natriuresis,** there is a decrease in ECF volume and blood volume, which in turn brings the arterial blood pressure back to normal level.

When blood pressure decreases, the reabsorption of water from renal tubules is increased. This in turn, increases ECF volume, blood volume and cardiac output, resulting in restoration of blood pressure.

## Through Renin-Angiotensin Mechanism

***Actions of Angiotensin II***

When blood pressure and ECF volume decrease, renin secretion from kidneys is increased. It converts angiotensinogen into angiotensin I. This is converted into angiotensin II by ACE (angiotensin-converting enzyme).

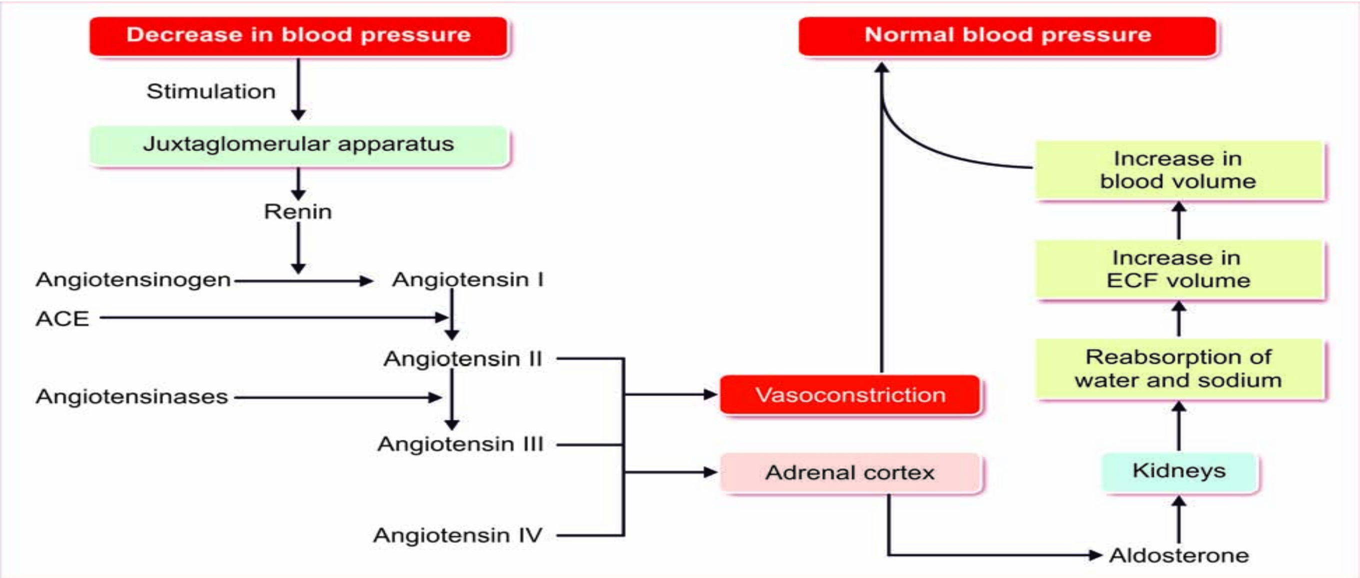
Angiotensin II acts in two ways to restore the blood pressure:

i. It causes constriction of arterioles in the body so that the peripheral resistance is increased and blood pressure rises. In addition, angiotensin II causes constriction of afferent arterioles in kidneys, so that glomerular filtration reduces. This results in retention of water and salts, increases ECF volume to normal level. This in turn increases the blood pressure to normal level.

ii. Simultaneously, angiotensin II stimulates the adrenal cortex to secrete aldosterone. This hormone increases reabsorption of sodium from renal tubules. Sodium reabsorption is followed by water reabsorption, resulting in increased ECF volume and blood volume. It increases the blood pressure to normal level.

***iii. Actions of Angiotensin III and Angiotensin IV***

Like angiotensin II, the angiotensins III and IV also increase the blood pressure and stimulate adrenal cortex to secrete aldosterone




**Regulation of blood pressure by renin-angiotensin mechanism. ACE = Angiotensin-converting enzyme.**

Mean arterial pressure is regulated b changes in cardiac output and systemic vascular resistance.

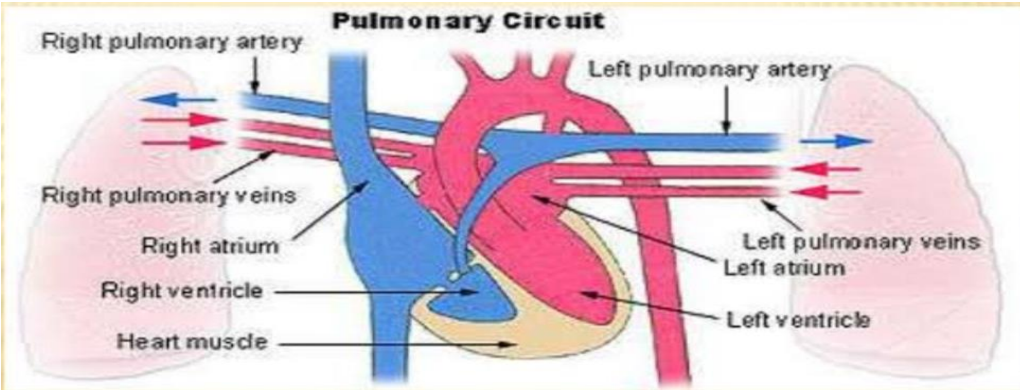
Cardiac output is determined by the product of stroke volume and heart rate. Stroke volume is determined by inotropy and ventricular preload. (The effects of afterload on stroke volume are not shown in his figure.)

## Pulmonary circulation

- The pulmonary circulation is the portion of the circulatory system which carries deoxygenated blood away from the right ventricle, to the lungs, and returns oxygenated blood to the left atrium and ventricle of the heart.
- Pulmonary circulation carries deoxygenated blood away from the heart, to the lungs, and returns oxygenated blood back to the heart.

The term pulmonary circulation is readily paired and contrasted with the systemic circulation. The vessels of the pulmonary circulation are pulmonary arteries and the pulmonary veins.

A separate system known as the bronchial circulation supplies oxygenate blood to the tissue of the large airways of the lungs.




### Structure

3D rendering of a high resolution computed tomography of the thorax. The anterior thoracic wall, the airways and the pulmonary vessels anterior to the root of the lung have been digitally removed in order to visualize the different levels of the pulmonary circulation.

Image showing main pulmonary artery coursing ventrally to the aortic root and trachea. The right pulmonary artery passes dorsally to the ascending aorta, while the left pulmonary artery passes ventrally to the descending aorta.

Deoxygenated blood leaves the heart, goes to the lungs, and then re-enters the heart; Deoxygenated blood leaves through the right ventricle through the pulmonary artery. From the right atrium, the blood is pumped through the tricuspid valve (or right atrioventricular valve), into the right ventricle. Blood is then pumped from the right ventricle through the pulmonary valve and into the main pulmonary artery.

**Lungs**

The pulmonary arteries carry deoxygenated blood to the lungs, where carbon dioxide is released and oxygen is picked up during respiration. Arteries are further divided into very fine capillaries which are extremely thin-walled. The pulmonary vein returns oxygenated blood to the left atrium of the heart.

**Veins**

The oxygenated blood then leaves the lungs through pulmonary veins, which return it to the left part of the heart, completing the pulmonary cycle. This blood then enters the left atrium, which pumps it through the mitral valve into the left ventricle. From the left ventricle, the blood passes through the aortic valve to the aorta. The blood is then distributed to the body through the systemic circulation before returning again to the pulmonary circulation.

**Arteries**

From the right ventricle, blood is pumped through the semilunar pulmonary valve into the left and right main pulmonary arteries (one for each lung), which branch into smaller pulmonary arteries that spread throughout the lungs.

**Development**

The pulmonary circulation loop is virtually bypassed in fetal circulation. The fetal lungs are collapsed, and blood passes from the right atrium directly into the left atrium through the foramen ovale: an open conduit between the paired atria, or through the ductus arteriosus: a shunt between the pulmonary artery and the aorta. When the lungs expand at birth, the pulmonary pressure drops and blood is drawn from the right atrium into the right ventricle and through the pulmonary circuit. Over the course of several months, the foramen ovale closes, leaving a shallow depression known as the fossa ovalis.

**Clinical significance-**

A number of medical conditions can affect the pulmonary circulation.

- **Pulmonary hypertension** describes an increase in resistance in the pulmonary arteries
- **Pulmonary embolus** is a blood clot, usually from a deep vein thrombosis that has lodged in the pulmonary vasculature. It can cause difficulty breathing or chest pain, is usually diagnosed trough a CT pulmonary angiography or V/Q scan, and is often treated with anticoagulants such as heparin and warfarin.
- **Cardiac shunt** is an unnatural connection between parts of the heart that leads to blood flow that bypasses the lungs.

## Circle of Willis

The Circle of Willis (also called Willis' circle, loop of Willis, cerebral arterial circle, and Willis polygon) is a circular anastomosis that supplies blood to the brain and surrounding structures.

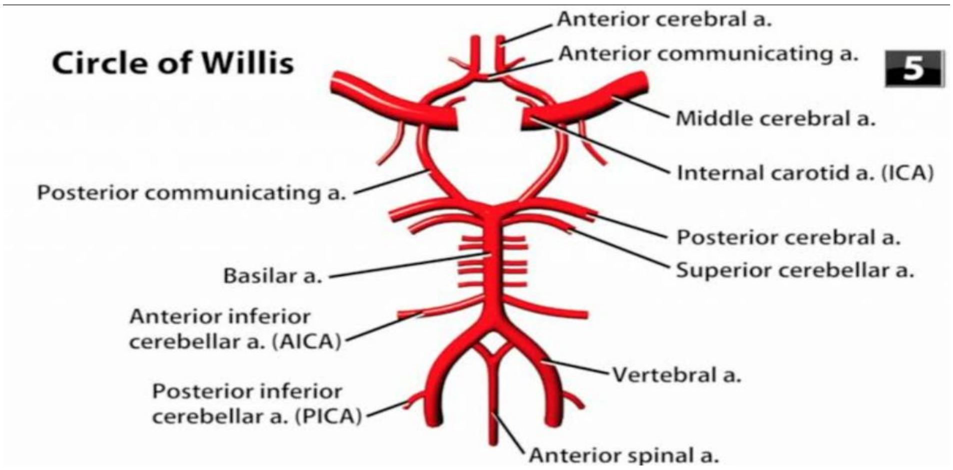
The Circle of Willis is the joining area of several arteries at the bottom (inferior) side of the brain. At the Circle of Willis, the internal carotid arteries branch into smaller arteries that supply oxygenated blood to over 80% of the cerebrum.

**Structure**

The Circle of Willis is a part of the cerebral circulation and is composed of the following arteries:

- Anterior cerebral artery (left and right)
- Anterior communicating artery
- Internal carotid artery (left and right)
- Posterior cerebral artery (left and right)
- Posterior communicating artery (left and right)

The middle cerebral arteries, supplying the brain, are not considered part of the circle of Willis.




## Origin of arteries

The left and right internal carotid arteries arise from the left and right common carotid arteries.

The posterior communicating artery is given off as a branch of the internal carotid artery just before it divides into its terminal branches - the anterior and middle cerebral arteries. The anterior cerebral artery forms the anterolateral portion of the circle of Willis, while the middle cerebral artery does not contribute to the circle.

The right and left posterior cerebral arteries arise from the basilar artery, which is formed by the left and right vertebral arteries. The vertebral arteries arise from the subclavian arteries.

The anterior communicating artery connects the two anterior cerebral arteries and could be said to arise from either the left or right side.

All arteries involved give off cortical and central branches. The central branches supply the interior of the circle of Willis, more specifically, the Interpeduncular fossa. The cortical branches are named for the area they supply. Since they do not directly affect the circle of Willis, they are not dealt with here

## Clinical significance

## Subclavian steal syndrome

The redundancies that the Circle of Willis introduce can also lead to reduced cerebral perfusion. In subclavian steal syndrome, blood is “stolen” from the circle of Willis to preserve blood flow to the upper limb.

Subclavian steal syndrome results from a proximal stenosis (narrowing) of the subclavian artery, an artery supplied by the aorta, which is also the same blood vessel that eventually feeds the circle of Willis via the vertebral and internal carotid arteries.

## Splanchnic circulation

Splanchnic is usually used to describe organs in the abdominal cavity.

It is used when describing:

- Splanchnic tissue
- Splanchnic organs- including the stomach, small intestine, large intestine, pancreas, spleen, liver, and may also include the kidney.
- Splanchnic nerves
- Splanchnic mesoderm
- Splanchnic circulation- the circulation of the gastrointestinal tract originating at the celiac trunk originating at the celiac trunk, the superior mesenteric artery and the inferior mesenteric artery.

The term ‘splanchnic circulation’ describes the blood flow to the abdominal gastrointestinal organs including the <u>stomach, liver, spleen, pancreas, small intestine, and large intestine.</u>

It comprises three major branches of the abdominal aorta;

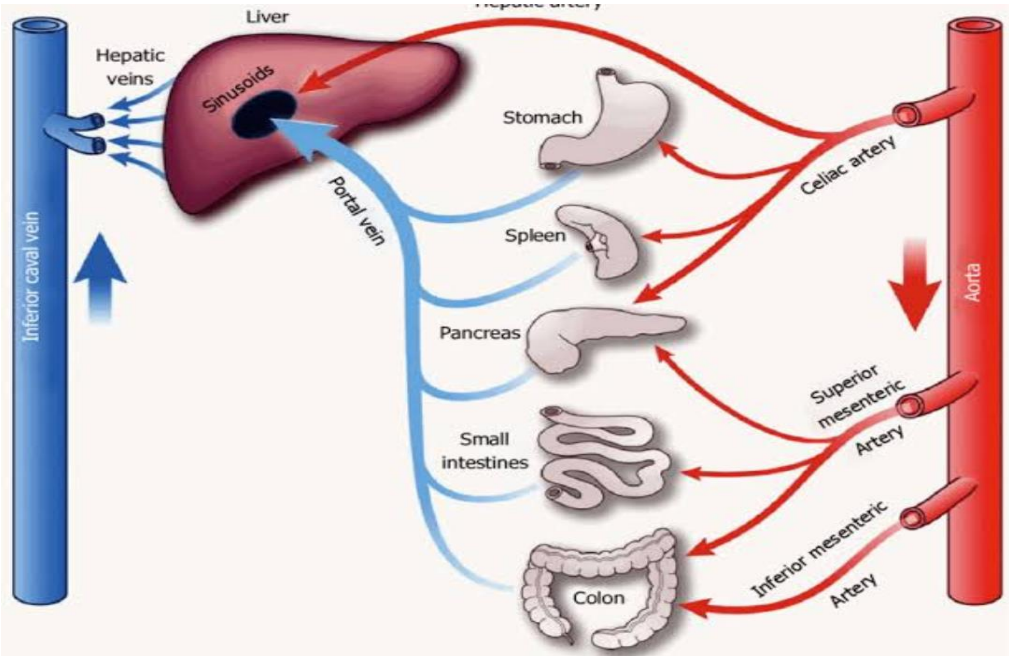
the coeliac artery;

superior mesenteric artery (SMA); and inferior mesenteric

Splanchnic or visceral circulation constitutes three portions:
1. Mesenteric circulation supplying blood to GI tract
2. Splenic circulation supplying blood to spleen
3. Hepatic circulation supplying blood to liver.
Unique feature of splanchnic circulation is that the blood from mesenteric bed and spleen forms a major amount of blood flowing to liver. Blood flows to liver from GI tract and spleen through portal system.

**Distribution of Blood Flow**
Stomach: 35 mL/100 g/minute

Intestine: 50 mL/100 g/minute
Pancreas: 80 mL/100 g/minute.




**<u>Regulation of Mesenteric Blood Flow</u>**

Mesenteric blood flow is regulated by the following factors:

**1. Local Auto regulation**

Local auto regulation is the primary factor regulating blood flow through mesenteric bed

**2. Activity of Gastrointestinal Tract**

Contraction of the wall of the GI tract reduces blood flow due to compression of blood vessels. And relaxation of wall of GI tract increases the blood flow due to removal of compression on the vessel wall.

**3. Nervous Factor**

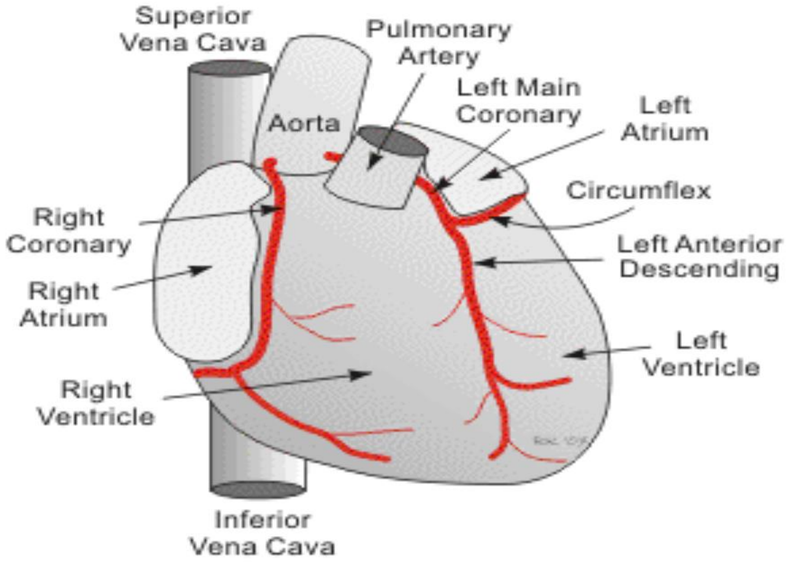
Mesenteric blood flow is regulated by sympathetic nerve fibers. Increase in sympathetic activity as in the case of emotional conditions or **'fight and flight reactions'** constrict the mesenteric blood vessels. So, more blood is diverted to organs like skeletal muscles, heart and brain, which need more blood during these conditions. Parasympathetic nerves do not have any direct action on the mesenteric blood vessels. But these nerves increase the contraction of GI tract which compresses the blood vessels, resulting in reduction in blood flow.

**4. Chemical Factors – Functional Hyperemia**

Functional hyperemia is the increase in mesenteric blood flow immediately after food intake. It is mainly because of **gastrin** and **cholecystokinin** secreted after food intake. In addition to these two GI hormones, digestive products of food substances such as glucose and fatty acids also cause vasodilatation and increase the mesenteric blood flow.

## Coronary circulation

Coronary circulation is the circulation of blood in the blood vessels that supplies and drains the heart muscle (myocardium). Coronary arteries supply oxygenated blood to the heart muscle and cardiac veins drain away the blood once it has been deoxygenated. Because the rest of the body, and most especially the brain, need a steady supply of oxygenated blood that is free of all but the slightest interruptions, the heart is required to function continuously. Interruptions of coronary circulation quickly cause heart attacks (myocardial infarctions), in which the heart muscle is damaged by oxygen starvation.




## Distribution Of Coronary Blood Vessels

Coronary Arteries

Heart muscle is supplied by two coronary arteries, namely -right and left coronary arteries, which are the first branches of aorta. Arteries encircle the heart in the manner of a **crown,** hence the name coronary arteries (Latin word corona = crown).

**Right and Left Coronary Arteries**

Right coronary artery supplies whole of the right ventricle and posterior portion of left ventricle.

Left coronary artery supplies mainly the anterior and lateral parts of left ventricle. There are many variations in diameter of coronary arteries.

## Branches of Coronary Arteries

Coronary arteries divide and subdivide into smaller branches, which run all along the surface of the heart. Smaller branches are called **epicardiac arteries** and give rise to further smaller branches known as **final arteries** or **intramural vessels.** Final arteries run at right angles through the heart muscle, near the inner aspect of wall of the heart.

## Clinical relevance-

Coronary artery disease or coronary heart disease (CHD) is a leading cause of death. It describes a reduction in blood flow to the myocardium and has several causes and consequences. It can result in reduced blood flow to the heart as a result of narrowing or blockage of the coronary arteries. This may be due to atherosclerosis, thrombosis, high blood pressure, diabetes or smoking.

A blockage in a coronary artery can be rapidly identified by performing a coronary angiogram.

Immediate treatment of a blockage can be performed by way of a coronary angioplasty, which involves he inflation of a balloon within the affected artery

# Cutaneous circulation

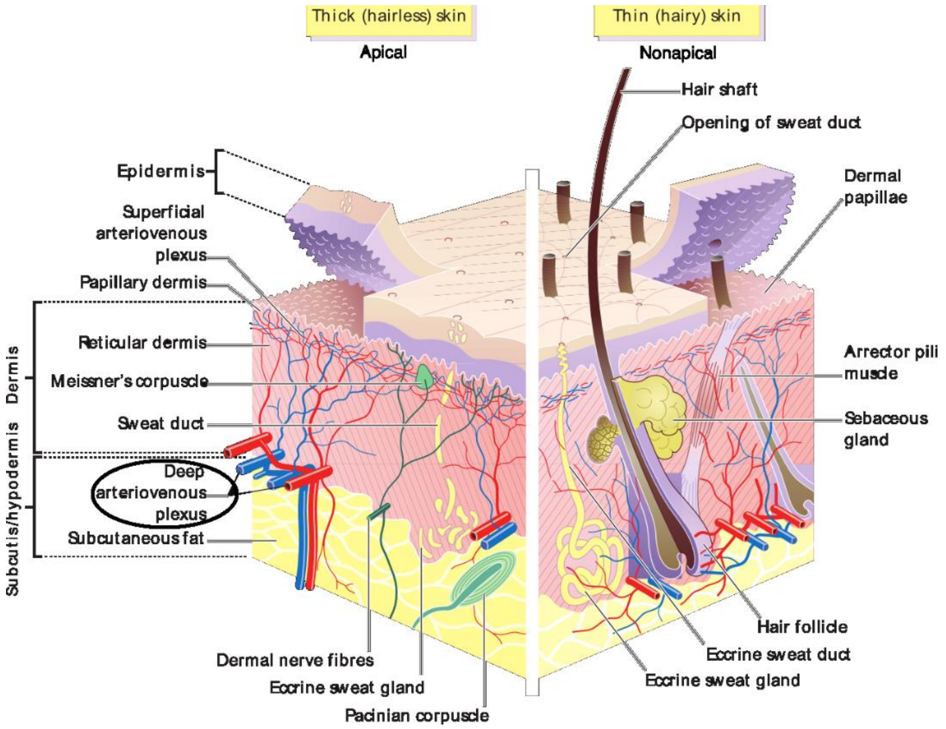
The cutaneous circulation is the circulation and blood supply of the skin. The skin is not a very metabolically active tissue and has relatively small energy requirements, so is blood supply is different to that of other tissues. Some of the circulating blood volume in the skin will flow through will flow through arteriovenous anastomoses (AVAs) instead of capillaries.

## Architecture of Cutaneous Blood Vessels

Architecture of cutaneous blood vessels is formed in the following manner:

1. **Arterioles** arising from the smaller arteries reach the base of **papillae of dermis**.
2. Then, these arterioles turn horizontally and give rise to **meta-arterioles**.

3. From meta-arterioles, hairpin-shaped **capillary loops** arise. Arterial limb of the loop ascends vertically in the papillae and turns to form a venous limb, which descends down.
4. After reaching the base of papillae, few venous limbs of neighbouring papillae unite to form the **collecting venule**.
5. Collecting venules anastomose with one another form the **subpapillary venous plexus**.
6. Subpapillary plexus runs horizontally beneath the bases of papillae and drain into **deeper veins.**




## Functions of Cutaneous Circulation

Cutaneous blood flow performs two functions:
1. Supply of nutrition to skin
2. Regulation of body temperature by heat loss.

## Regulation of Cutaneous Blood Flow

Cutaneous blood flow is regulated mainly by body temperature. Hypothalamus plays an important role in regulating cutaneous blood flow. When body temperature increases, the hypothalamus is activated. Hypothalamus in turn causes cutaneous vasodilatation by acting through medullary vasomotor centre. Now, blood flow increases in skin. Increase in cutaneous blood flow causes the loss of heat from the body through sweat. When body temperature is low, vasoconstriction occurs in the skin. Therefore, the blood flow to skin decreases and prevents the heat loss from skin.

## Cardiovascular Adjustment That Occurs During Exercise

During exercise, there is an increase in metabolic needs of body tissues, particularly the muscles.
Various adjustments in the body during exercise are aimed at:
1. Supply of various metabolic requisites like nutrients and oxygen to muscles and other tissues involved in exercise
2. Prevention of increase in body temperature.

### Types of Exercise

Exercise is generally classified into two types depending upon the type of muscular contraction:
1. Dynamic exercise
2. Static exercise.

Cardiovascular changes are slightly different in these two types of exercise.

### Dynamic Exercise

Dynamic exercise primarily involves the **isotonic muscular contraction.**
It keeps the joints and muscles moving. Examples are swimming, bicycling, walking, etc. Dynamic exercise involves **external work,** which is the shortening of muscle fibers against load.
In this type of exercise, the heart rate, force of contraction, cardiac output and systolic blood pressure increase. However, the diastolic blood pressure is unaltered or decreased. It is because, during dynamic exercise, peripheral resistance is unaltered or decreased depending upon the severity of exercise.

### Static Exercise

Static exercise involves **isometric muscular contraction** without movement of joints. Example is pushing heavy object. Static exercise does not involve **external work.** During this exercise, apart from increase in heart rate, force of contraction, cardiac output and systolic blood pressure, the diastolic blood pressure also increases. It is because of increase in peripheral resistance during static exercise.

### Aerobic and Anaerobic Exercises

Based on the type of metabolism involved, exercise is classified into two types:
1. Aerobic exercise
2. Anaerobic exercise.

The terms aerobic and anaerobic refer to the energy producing process during exercise. Aerobic means **‘with air’** or **‘with oxygen’.** Anaerobic means **‘without air’** or **‘without oxygen’.** Both aerobic and anaerobic exercises are required to maintain physical fitness.

**Aerobic Exercise**

Aerobic exercise involves activities with lower intensity, which is performed for longer period. The energy is obtained by utilizing nutrients in the presence of oxygen and hence it is called aerobic exercise. At the beginning, the body obtains energy by burning glycogen stored in liver. After about 20 minutes, when stored glycogen is exhausted the body starts burning fat. Body fat is converted into glucose, which is utilized for energy. Aerobic exercise requires large amount of oxygen to obtain the energy needed for prolonged exercise.
Examples of aerobic exercise: Fast walking, Jogging, Running, Bicycling, Skiing, Badminton, Swimming, Rowing.

**Anaerobic Exercise**

Anaerobic exercise involves exertion for short periods followed by periods of rest. It uses the muscles at high intensity and a high rate of work for a short period. Body obtains energy by burning glycogen stored in the muscles without oxygen hence it is called anaerobic exercise. Burning glycogen without oxygen liberates lactic acid. Accumulation of lactic acid leads to fatigue. Therefore, this type of exercise cannot be performed for longer period. And a recovery period is essential before going for another burst of anaerobic exercise. Anaerobic exercise helps to increase the muscle strength.
Examples of anaerobic exercise: Pull-ups, Push-ups, Weightlifting, Sprinting, Any other rapid burst of strenuous exercise.

**METABOLISM IN AEROBIC AND ANAEROBIC EXERCISES**

When a person starts doing some exercise like jogging, bicycling or swimming, the muscles start utilizing energy. In order to have quick energy during the first few minutes, the muscles burn glycogen stored in them. During this period, fat is not burnt. Only glycogen is burnt and it is burnt without using oxygen. This is called **anaerobic metabolism.** Lactic acid is produced during this period. Presence of lactic acid causes some sort of burning sensation in the muscles particularly the muscles of arms, legs and back. Muscles burn all the muscle glycogen within 3 to 5 minutes. If the person continues the exercise beyond this, glycogen stored in liver is converted into glucose, which is transported to muscles through blood. Now the body moves into **aerobic metabolism.** The glucose obtained from liver is burnt in the presence of oxygen. No more lactic acid is produced. So the burning sensation in the muscles disappears. Proper breathing is essential during this period so that adequate oxygen is supplied to the muscles to extract the energy from glucose. The supply of glucose from

liver in combination with adequate availability of oxygen allows the person to continue the exercise.
Utilization of all the glycogen stored in liver is completed by about 20 minutes. If the exercise is continued beyond this, the body starts utilizing the fat. The stored fat called body fat is converted into carbohydrate, which is utilized by the muscles. This allows the person to do the exercise for a longer period.

## Effects of Exercise On Cardiovascular System

### 1. On Blood
Mild hypoxia developed during exercise stimulates the juxtaglomerular apparatus to secrete erythropoietin. It stimulates the bone marrow and causes release of red blood cells. Increased carbon dioxide content in blood decreases the pH of blood.

### 2. On Blood Volume
More heat is produced during exercise and the thermo-regulatory system is activated. This in turn, causes secretion of large amount of sweat leading to:
i. Fluid loss
ii. Reduced blood volume
iii. Hemoconcentration
iv. Sometimes, severe exercise leads to even dehydration.

### 3. On Heart Rate
Heart rate increases during exercise. Even the thought of exercise or preparation for exercise increases the heart rate. It is because of impulses from cerebral cortex to medullary centers, which reduces vagal tone. In moderate exercise, the heart rate increases to 180 beats/minute. In severe muscular exercise, it reaches 240 to 260 beats/minute. Increased heart rate during exercise is mainly because of **vagal withdrawal.** Increase in sympathetic tone also plays some role.

Increased heart rate during exercise is due to four factors:
i. Impulses from proprioceptors, which are present in the exercising muscles; these impulses act through higher centers and increase the heart rate
ii. Increased carbon dioxide tension, which acts through medullary centers
iii. Rise in body temperature, which acts on cardiac centers via hypothalamus, increased temperature also stimulates SA node directly
iv. Circulating catecholamines, which are secreted in large quantities during exercise.

### 4. On Cardiac Output
Cardiac output increases up to 20 L/minute in moderate exercise and up to 35 L/minute during severe exercise. Increase in cardiac output is directly

proportional to the increase in the amount of oxygen consumed during exercise. During exercise, the cardiac output increases because of increase in heart rate and stroke volume. Heart rate increases because of **vagal withdrawal.**
Stroke volume increases due to increased force of contraction. Because of vagal withdrawal, sympathetic activity increases leading to increase in rate and force of contraction.

**5. On Venous Return**

Venous return increases remarkably during exercise because of muscle pump, respiratory pump and splanchnic vasoconstriction.

**6. On Blood Flow To Skeletal Muscles**

There is a great increase in the amount of blood flowing to skeletal muscles during exercise. In resting condition, the blood supply to the skeletal muscles is 3 to 4 mL/100 g of the muscle/minute. It increases up to 60 to 80 mL in moderate exercise and up to 90 to 120 mL in severe exercise. During the muscular activity, stoppage of blood flow occurs when the muscles contract. It is because of compression of blood vessels during contraction. And in between the contractions, the blood flow increases. Sometimes the blood supply to muscles starts increasing even during the preparation for exercise. It is due to the sympathetic activity. Sympathetic nerves cause vasodilatation in muscles. The sympathetic nerve fibers causing vasodilatation in skeletal muscle are called **sympathetic cholinergic fibers** since these fibers secrete **acetylcholine** instead of noradrenaline.

**7. On Blood Pressure**

During moderate isotonic exercise, the systolic pressure is increased. It is due to increase in heart rate and stroke volume. Diastolic pressure is not altered because peripheral resistance is not affected during moderate isotonic exercise.

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