Learning unit 10: Circulation and gas exchange

10.1 Introduction

To complete the learning unit, you will need to refer to pages 1003–1032 chapter 43 in Campbell et al. (2015)

Living organisms require nutrients and oxygen to survive; circulatory and respiratory systems help assure that nutrients and oxygen is distributed throughout the body. The presence of a circulatory system reduces the distance a substance must diffuse to enter or leave the cell. The circulatory system does more than move gases; it is a critical component to maintain homeostasis of the body.

10.2 Learning outcomes

By the end of this learning unit you should be able to

• explaining why animals need circulatory systems

• distinguishing between the different types of circulatory systems and describing their structural components

• explaining gas exchange in animals in terms of:

- general requirements
- adaptations
- differences between animals with different lifestyles

10.3 Circulatory systems link exchange surfaces with cells throughout the body

Recommended reading: pages 1002–1004 of chapter 43 in Campbell et al. (2015)

Certain invertebrates have cells that exchange oxygen and nutrients directly with the surrounding medium. Other animals have a circulatory system that moves fluid between each cell's immediate surroundings and the tissues where exchange with the environment occurs.

10.3.1 Gastrovascular cavities

Animals consisting of gastrovascular cavities are those that lack a distinct circulatory system (e.g. hydras, and jellies). In these organisms an opening at one end connects the cavity to the surrounding water. Animals with gastrovascular cavity have fluid that bathes both the inner and outer tissue layers.

10.3.2 Evolutionary variation in circular systems

Circulatory systems have three basic components: a circulatory fluid, a set of interconnecting vessels, and a muscular pump (the heart).

Arthropods and most molluscs have an open and circulatory systems, this means that they have circulatory fluid that bathes the organs directly. This fluid is referred to as hemolymph. In a closed circulatory system, a circular fluid called blood is confined to vessels. One or more hearts pump blood into large vessels that branch into smaller ones that infiltrate the organs.

10.3.3 Organization of vertebrate circular systems

The closed circulatory system of humans and other vertebrates is often called the cardiovascular system. Arteries, veins, and capillaries are the three main types of blood vessels. The arteries carry blood away from the heart to organs; capillaries are microscopic vessels called capillary beds, they infiltrate every tissue in the body. Capillaries converge into venules which in turn converge into veins; then the veins carry blood back to the heart.

Bony fishes and sharks consist of two heart chambers: an atrium and a ventricle whereby the blood passes through the heart once in each complete cycle. This phenomenon is called single circulation.

Double circulation occurs in amphibians, reptiles and mammals. In this arrangement the pumps for the two circuits are combined into a single organ (the heart).

10.4 Coordinated cycles of heart contraction drive double circulation in mammals

Recommended reading: pages 1006–1008 of chapter 43 in Campbell et al. (2015)

10.4.1 Mammalian circulation

We will first look at the pulmonary circuits. Contraction of the right ventricle pumps blood to the lungs via the pulmonary arteries. As it passes through the capillary beds in the lungs, oxygen is loaded and carbon dioxide is unloaded. Oxygen rich blood return to the left atrium of the heart via the pulmonary veins. Then the then the oxygen-rich blood is pumped into the heart's left ventricle which pumps the oxygen-rich blood to the body tissues via the aorta.

10.4.2 A closer look at the mammalian heart

The heart contracts and relaxes and relaxes in a rhythmic cycle. When it contracts its pumps blood; when it relaxes, its chambers are filled with blood. A complete sequence of pumping and filling is called cardiac cycle. The contraction phase of the cardiac cycle is referred to as systole, and the relaxation phase is known as diastole. The volume of blood that each ventricle pumps per minute is known as cardiac output. The cardiac output is affected by rate of contraction (heart rate), and the stroke volume (amount of blood pumped by the ventricle in a single contraction).

The heart has valves the control the direction of flow of blood during cardiac cycles. An atrioventricular (AV) valve lies between each atrium and ventricle. These valves keep blood from flowing back into the atria. Semilunar valves are located at the two exits of the hearts; where aorta leaves the left ventricle and where the pulmonary artery leaves the right ventricle.

10.4.3 Maintaining the heart's rhythmic beat

In vertebrates, the heartbeat originates in the heart itself. Some cardiac muscles contract and relax repeatedly without any signal from the nervous system. this phenomenon is known as autorhythmic, and it is possible due to the presence of autorhythmic cells located at the wall of the atrium near were the superior vena cava enters the heart. This cluster of cells is called sinoatrial (SA) node, or pacemaker. The SA node causes contraction of both atria to occur.

After contraction of the atria, the signal that originated from the SA node now reach another set of autorhythmic cells that are located at the wall between the left and right atria. These cells form a relay point called the atrioventricular (AV) node that causes the ventricles to contract.

10.5 Patterns of blood pressure and flow reflect the structure and arrangement of blood vessels

Recommended reading: pages 1009–1013 of chapter 43 in Campbell et al. (2015)

10.5.1 Blood vessels structure and function

Blood vessels contain a central lumen (cavity) lined with an endothelium; in which the capillaries have a thinner layer of the smooth endothelium to minimise resistance.

10.5.2 Blood flow velocity

The blood flow is affected by the diameter of the vessels; arteries have a smaller diameter as compared to veins, thus blood flow is much higher in the arteries.

10.5.3 Blood pressure

Blood pressure is generated by the contractions of the heart. Arterial blood pressure is the highest when the heart contracts during ventricular systole. The pressure at this point is called systolic pressure. Diastolic pressure is low, and occurs when the ventricles are relaxed.

Blood pressure changes depending on the physical or emotional state of the body. This is triggered by hormonal responses that cause smooth muscles in arteriole walls to contract (this is known as vasoconstriction). Narrowing of the arterioles increases pressure upstream in the arteries. When the smooth muscles relax, the arterioles undergo vasodilation; increase in the diameter of the arterioles causes a fall in the blood pressure of the arteries.

10.5.4 Capillary function

Capillaries play a role in directing blood flow where needed or when required. For example blood flow to the skin is promoted when it’s hot as to control the body temperature, and also blood flow to the digestive tract increases after a meal. During strenuous exercise blood flow will be redirected to the skeletal muscles and diverted from the digestive tract. The redirecting of blood flow in capillaries is due to the precapillary sphincters that prevent blood flow to the capillary beds when they contract.

10.5.5 Fluid return by the lymphatic system

The is a fluid that normally leaks out of the capillaries, and the lymphatic system is responsible for returning that fluid back to the blood. The fluid lost from the blood is called lymph. The lymphatic system drains into large veins of the circulatory system at the base of the neck.

The lymphatic system also branches out in a system of tubes called lymph vessels. Along the lymph vessels are organs lymph nodes. These organs house cells that attack viruses and bacteria.

10.6 Blood components function in the exchange, transport, and defence

Recommended reading: pages 1014–1017 of chapter 43 in Campbell et al. (2015)

10.6.1 Blood composition and function

Vertebrates’ blood is a connective tissue consisting of cells suspended in a liquid matrix called plasma.

The blood contains two classes of cells: red blood cells which transport oxygen, and white blood cells which function in defence. Also suspended in blood plasma are platelets; these are fragments of cells that are involved in the clotting process.

10.6.2 Cardiovascular disease

Involve disturbances in heart valve function to disruption in blood flow that could be fatal if it occurs to the brain or heart.

Cholesterol metabolism plays a central role in cardiovascular disease. Example of these cholesterol molecules are low-density lipoproteins (LDL) and high-density lipoproteins.

Atherosclerosis occurs due to high LDL levels and low HDL levels in the blood accompanied by inflammation.

10.7 Gas exchange occurs across specialized respiratory surfaces

Recommended reading: pages 1019–1022 of chapter 43 in Campbell et al. (2015)

Gas exchange is the uptake of molecular oxygen from the environment and the discharge of carbon dioxide to the environment.

10.7.1 Partial pressure Gradients in gas exchange

To understand the driving force s for gas exchange, we must calculate the partial pressure, which is the pressure exerted by a particular gas in a mixture of gases.

At sea level, the atmosphere exerts a downward force equal to that of column mercury (Hg) 760 mm high. This means that atmospheric pressure at sea level is 760mm High.

In order to get partial pressure of oxygen in the atmosphere, you have to consider the percentage of oxygen that is present in the total atmospheric volume (which is 21%). Then calculate the partial pressure as:

P_{O2} = 21% X 760 mm Hg (value of atmospheric pressure at sea level)

= 21/100 X 760 mm Hg

= 0.21 X 760 mm Hg

= 159.6 mm Hg

10.7.2 Respiratory media

Conditions for gas exchange are different depending on whether the respiratory medium (source of oxygen) is air or water.

10.7.3 Respiratory surfaces

The movement of oxygen and carbon dioxide across moist respiratory surfaces takes place entirely by diffusion.

10.7.4 Gills and aquatic animals

Gills are out folding of the body surface that is suspended in the water. Movement of respiratory medium over the respiratory surface is a process called ventilation.

10.7.5 Lungs

The lungs are localized respiratory organs that have respiratory surfaces that are not in direct contact with all other parts of the body; so the circulatory system bridges the gap and transports gases between the lungs and the rest of the body.

The mammalian respiratory system comprises of branching ducts that convey air to the lungs. Air enters through the nostrils and passes down to the pharynx which leads to the trachea or wind pipe. The trachea branches into two bronchi (bronchus for singular) which enter the lung. In the lung each bronchus further divide into finer and finer tubes called bronchioles. The tips of terminal bronchioles form alveoli (singular, alveolus). Gas exchange in mammals occurs in alveoli sacs.

10.8 Breathing ventilates the lungs

Recommended reading: pages 1024–1026 of chapter 43 in Campbell et al. (2015)

First inhalation in birds causes air to fill the posterior air sacs, then the bird exhales, by this the air that initially entered the posterior air sacs contract and push air into the lungs. On the second inhalation air passes through the lungs and fills the anterior air sacs. On the second exaltation at the anterior air sacs contract and push air from the first inhalation out of the body.

10.8.1 How a mammal breathes

Mammals employ a negative pressure breathing; whereby air is pulled into the lungs, rather than pushing it into the lungs. Expanding the thoracic cavity during inhalation involves the animal’s rib muscles and the diaphragm.

10.8.2 Control of breathing in humans

Most of the time breathing is regulated by involuntary mechanisms. This means that there are neurons (found in the medulla oblongata). The medulla oblongata regulates breathing with the use of the pH of the surrounding tissue fluids as an indicator of blood CO_2 concentration. As the pH in the blood decreases the medulla’s control circuits increase the depth and rate of breathing.

10.9 Adaptations for gas exchange include pigments that bind and transport gases

Recommended reading: pages 1027–1029 of chapter 43 in Campbell et al. (2015)

10.9.1 Respiratory pigments

Animals transport most of their O2 bound to the protein called respiratory pigments. These respiratory pigments are often contained within specialized cells; and they greatly increase the amount of oxygen that can be carried in the circulatory fluid.

The respiratory pigments have a distinct colour and consist of protein bound to metal (e.g. hemocyanin and haemoglobin). Haemoglobin occurs in all vertebrates and some invertebrates. This molecule transports oxygen and carbon dioxide.

10.10 Activity 10.1

Do this activity and add it to your portfolio.

Refer to your textbook and answer the following questions:

a) Why do you think arteries have a thicker connective tissue and smooth muscle layer as compared to the veins?

b) Why do you think veins have valves but arteries are not composed of any?

c) Show your calculation on partial pressure of Carbon dioxide and Nitrogen.

10.11 Feedback on activity 10.2

b. When the blood leaves the heart to the rest of the body, it enters the arteries that are narrow ad are filled with pressure. The arteries need to be able to withstand the pressure so the muscles and tissue around it need to be capable of withstanding pressure.
d. Since there is less pressure in the veins due to the wider diameter of the veins as compared to the arteries, blood is most capable of flowing back especially in the around that are found in the leg (gravity also plays a role). The valves simply prevent blood from flowing backwards.
f. With this type of question you need to find out what is the percentage of volume that carbon dioxide and nitrogen contribute to the total atmospheric air. Then multiply each percentage with the atmospheric pressure at sea level (which is 760 mm Hg).

10.12 Summary

Arthropods and most molluscs have an open circulatory system, and vertebrates have a closed circulatory system. The closed circulatory system is comprised of blood vessels, a heart, and blood. The heart has chambers: ventricles and atriums. These chambers are able to contract (pump) and relax (fill) due to presence of sinoatrial (SA) node and atrioventricular (AV) node, respectively.