Anatomy and physiology of blood and heart

The mechanism of the pumping action of the heart can be categorized in three phases- the generation of an action potential, conduction of the action potential and cardiac muscle contraction (action potential-contraction coupling). The action potential is generated the specialized autorythmic myocardial cells located at the Sino atria (SA) node. The potential spreads to the atria and enters the ventricles through the atria ventricular (AV) node from where it is conducted throughout the ventricles by the bundle of His and the purkinje fiber. The action potential triggers muscle contraction as it sweeps around the heart1.

As the cardiac muscles contract and relax the heart beats repeatedly, in the process receiving and pumping blood, first to the lungs then to the rest of the body. As it leaves the heart, the blood carries with it oxygen and nutrients to the body and brings back metabolic wastes from the body cells1, 2.

However, much as it supplies blood to the rest of the body, the heart itself needs blood to support its metabolic activity. The heart is thus supplied by the coronary arteries which branch off from the aorta. Reduction in the volume of this coronary flow can greatly impair the pumping action of the heart and if not treated, can cause heart failure. A number of treatment options ranging from surgical to drugs are available2b.

THE CARDIOVASCULAR SYSTEM

The cardiovascular system is an organ system responsible for distribution of nutrients and oxygen to the body’s cells and removal of metabolic byproducts from the cells. It consists of the following:

Blood which carries nutrients and oxygen to the cells and metabolic byproducts away from the cells

The blood vessels which are the pathways through which blood flows

The heart which receives and pumps blood. Embedded in the heart are valves that control blood flow and ensure that blood flows in a specified direction3, 8.

THE HEART

In brief, the heart is a muscular organ “ enclosed in a double walled sack called the pericardium”. It is about the size of a fist and weighs between 250 grams and 350 grams. It is located “ within the medial cavity of the thorax between the second and fifth intercostal space, just on the superior surface of the diaphragm”, anterior to the vertebral column and posterior to the sternum7.

The heart is divided in four chambers, the right and left atria, the right and left ventricle. The circulation process is such that the right atrium receives blood from the rest of the body through the venacavea and feeds it to the right ventricle which pumps it to the lungs through the pulmonary artery to be oxygenated. Blood from the lungs comes back to the left atrium through the pulmonary vein and finally to the left ventricle. The left ventricle pumps blood to the rest of the body though the aorta and arteries7, 1.

The Mechanism of Heart function

The most important function of the heart is to pump blood. The mechanism by which the heart pumps blood can be understood by examining the events

that lead to cardiac muscle contraction. The contraction process starts with the generation of an action potential from the sinoatrial (SA) node giving rise to a depolarization wave. The wave spreads through the atria, entering the ventricles through the atrioventricular (AV) node and is conducted throughout the ventricles by the bundle of His and the purkinje fibers1.

Generation of action potential.

The heart is composed of two kinds of cardiac muscle cells- the contractile and autorythmic cells. The contractile cells are responsible for the mechanical work of pumping and therefore form the bulk of the cardiac muscles. However, these cells need to be excited before they can contract. Highly specialized autorythmic cells are responsible for generation and conduction of the excitation signal-the action potential1, 3. These autorythmic cells are found in specific regions of the heart that include:

The SA node. This is a small region located at the upper wall of the right atrium.

The AV node. This is a bundle of the autorythmic cells found at the lower wall of the right atrium, near the septum that separates the atria from the ventricles.

The bundle of His. This is a bundle of specialized conductive cells that originate from the AV node and runs down the septum between the ventricles. It separates into the right and left bundles serving the respective ventricles.

The purkinje fiber. These can be regarded as terminations of the bundle of His. They spread over the base of the ventricles. The locations of the autorythmic cells are the origin and pathways of the action potential3.

The cardiac action potential

The SA node is the pace maker of the heart. It sets the frequency at which the heart beats. Looking at the cardiac cell, the action potential starts by the reorganization of the intracellular and extracellular concentration of potassium, sodium, chloride and calcium ions due to changes in the cell membrane permeability. A graph showing a typical myocardial cell action potential is shown in figure 1 below.

Figure 1: Cardiac cell action potential. Source4:

As in the graph, the different phases represent different stages of depolarization of the cardiac cell.

Phase 4: In this phase, the cell is at rest. In the resting state, the cell membrane is more permeable to potassium and therefore the resting potential is more or less equal to the potassium equilibrium potential (-90mV).

Phase 0: As the potential slowly rises, the voltage-gated sodium channels open leading to a rapid influx of potassium into the cell causing rapid depolarization. At the same time, the membrane permeability to potassium slowly reduces as the potassium channels close. This process takes the membrane potential to around +20Mv before the sodium channels suddenly close.

Phase 1: On inactivation of the sodium channels, potassium continues to leak out of the cell and chloride ions go into the cell causing a small downward deflection of the action potential.

Phase 2: At this stage, there is increased permeability of the membrane to calcium ions. The inward calcium movement is balanced by an outward movement of potassium ions accounting for the relatively flat phase 2.

Phase 3: An increase in the permeability of potassium outweighs the inward calcium current and eventually tips the potential of the cell. This is the repolarization phase and the cell goes back to its resting potential, phase 43, 4.

Excitation-contraction coupling

As described in muscle contraction, the action potential-contraction coupling is due to the release of calcium from the cell's sarcoplasmic reticulum. The calcium combines with troponin which regulates the tropomyosin, removing

it from the binding site. This allows myosin to bind to actin thus making the muscle to contract3.

The cardiac cycle

The depolarization and repolarization of the cardiac cell described above triggers the contraction and relaxation to the atria and ventricles of the cell. The cardiac cycle is divided in two main phases, diastole which is the period of relaxation and systole which is the period of contraction.

Systole. During this phase, the depolarization wave starts from the SA node, spreading first through the atria and causing the atria to contact first. This forces blood from the atria to the ventricles. At this time, the atrioventricular valves are open while the pulmonary and aortic valves are closed. The depolarization wave then enters the ventricles through the AV node, spreading over all the ventricles via the specialized conductive bundle of His and the purkinje network. This causes the ventricles to contract forcing the blood to the lungs through the pulmonary vein and the rest of the body through the aorta. Here the atrioventricular valves close while the pulmonary and aortic valves open5, 3.

Diastole. After contraction of the atria, the cells are repolarized. This allows the atria to relax thus allowing blood to flow into them through the vena cavea. After the ventricular contraction, the ventricles also relax awaiting to be filled with blood from the atria5.

THE CIRCULATORY SYSTEM

The circulatory system is part of the cardiovascular system and is divided into the pulmonary circulation and systemic circulation.

The pulmonary circulation transports deoxygenated blood from the heart to the lungs and returns oxygenated blood from the lungs to the heart9.

The systemic circulation transports oxygenated blood from the heart to the rest of the body and brings back deoxygenated blood from the body back to the heart9.

Deoxygenated blood enters the right atrium from the vena cava and flows through the tricuspid valve into the right ventricle. It is pumped from the right ventricle through the pulmonary semilunar valve into the pulmonary arteries which go to the lungs. Oxygenated blood returns via the pulmonary veins and enters the left ventricle through the mitral valve. It is the pumped through the aortic valve, to the aorta then through the arteries to the rest of the body. It is evident that oxygen is very important in metabolic activity of the body cells3, 9.

Transport of oxygen by the cardiovascular system

The red blood cells.

One of the functions of the cardiovascular system is to distribute oxygen around the body. Oxygen is carried in blood by the red blood cells. Understanding the structure of the red blood cells will help us to understand how it is able to carry oxygen.

The molecule of a red blood cell is composed of four polypeptide chains with each polypeptide chain having an iron-containing heme group. “ Each of the four iron atoms can combine reversibly with oxygen” according to the equation:

O2+Hbâ†” HbO2. It is therefore possible that each molecule of hemoglobin can carry up to four molecules of oxygen1b, 2b.

Oxygen uptake

Blood is pumped from the right ventricle to the lungs to be oxygenated. In the alveoli, the partial pressure of oxygen is higher than that in the blood and the partial pressure of carbon dioxide in the alveoli is lower than that in the blood. The pressure differences make it possible for oxygen to diffuse from the alveoli to the blood, thus binding to the iron in the hemoglobin. Carbon dioxide on the other hand diffuses from the blood to the lungs. Carrying oxygen, blood is returned to the left atria then to the left ventricle which pumps it to the rest of the body2c.

Oxygen release:

In the tissues and organs, the cells are undergoing metabolism, continually consuming oxygen and releasing carbon dioxide. This means that the intracellular partial pressure of oxygen is lower than that in the blood and the intracellular partial pressure of carbon dioxide is higher than that in the blood. Again the pressure differences make it possible for oxygen to diffuse from the blood to the cells and carbon dioxide from the cells to the blood, binding again with the iron in the hemoglobin. Therefore, as blood flows around the body, it continually distributes oxygen2c, 6.

BLOOD SUPPLY TO THE HEART

Coronary flow

In order to perform its functions, the heart an abundant supply of oxygen and nutrients and therefore needs a dedicated supply of blood. Coronary

circulation is that part of the systemic circulation that provides blood supply to the heart. Just as the “ aorta leaves the left ventricle, it gives of the right and left coronary arteries” 9. The left coronary artery divides into smaller braches supplying blood to the apex and the posterior side of the heart, the ventricles and part of the anterior interventricular septum, the left atrium and posterior wall of the left ventricle. The right coronary artery supplies the lateral aspect of the right atrium and ventricle, the posterior wall of both ventricles and the SA node9, 10.

Effect of reduced coronary flow on cardiac function

“ The energy demand of the cardiac muscle is so crucial that an interruption of blood supply to any part of the myocardium can cause necrosis within minutes” 9. A decrease in coronary flow to levels below normal is called “ myocardial ischemia”. The ischemia can be caused by vascular spasms of the coronary arteries, atherosclerosis or increased activity of the heart beyond levels that the coronary arteries can supply10.

“ Temporary or reversible obstruction of coronary blood flow can cause chest pain known as angina pectoris” 9. Chronic myocardial ischemia can lead to myocardial infarction where myocardial cells die and are replaced by scar tissue. Reduced coronary flow therefore can affect cardiac function in several ways.

If the heart is not able to meet its metabolic demand, it can be understood that it will not be able to pump enough blood to the body. Reduced blood flow to the rest of the body can result in serious physiological and pathological conditions which are beyond the scope of this essay.

With the death of some cardiac cells as in the case of chronic ischemia, several other life threatening conditions can arise which affect cardiac function. One of such dangerous conditions is ventricular fibrillation which is an abnormal pulse generation triggered by the damaged myocardial cells. The heart will not be able to pump blood but will just quiver around without any net output. Death can occur within minutes2b, 6.

Treatment of reduced coronary flow

Other immediate effects like ventricular fibrillation caused by reduced coronary flow can be treated by defibrillation. However, the main cause of reduced coronary flow is coronary artery occlusion or restriction and the following treatment options are available:

Coronary bypass: This is a surgical technique where the occluded coronary artery is cut and replaced by a new blood vessel, usually a vein taken from somewhere in the patients body2b.

Coronary balloon angiography (cardiac catheterization): This is another surgical procedure where a catheter containing a balloon at its tip is passed into the occluded artery. The balloon is enlarged thus stretching the artery and opening it in the process2b.

The use vasodilator drugs such as nitroglycerine: These drugs dilate the coronary artery thereby lowering the total peripheral resistance. This reduces the work the heart must do in ejecting blood. This is usually given to people who have already suffered myocardial infarction to reduce the risk of another occurance2b, 10.

A person at risk of myocardial infarction can be put a low cholesterol, low fat diet to reduce the risk of atherosclerosis and takes aspirin to reduce the risk of blood clot formation.

Conclusion

The cardiovascular system is one of the most important systems of the body. All the other systems and organs of the body depend on it for supply of oxygen and nutrients and removal of metabolic wastes. The heart acts as a pump to make sure blood is circulated to all parts of the body through pulmonary and systemic circulations9. However, the heart itself needs supply of blood in order to perform its main function of pumping blood and the heart is supplied by the coronary circulation. Reduction in coronary flow means the heart will not be able to meet it metabolic needs and therefore cannot pump enough blood. This can adversely affect normal activity of the body and cause death10.

References

Sherwood L. Fundamentals of physiology a human perspective. St. Paul Minn: West publishing company; 1991. 190-199

1b. Sherwood L. Fundamentals of physiology a human perspective. St. Paul Minn: West publishing company; 1991. 263-266

Vander A, Sherman J, Luciano D. Human physiology, the mechanisms of body function, seventh edition. Boston: McGrow-Hill; 1998. 387-389.

2b. Vander A, Sherman J, Luciano D. Human physiology, the mechanisms of body function, seventh edition. Boston: McGrow-Hill; 1998. 374-377.

2c. Vander A, Sherman J, Luciano D. Human physiology, the mechanisms of body function, seventh edition. Boston: McGrow-Hill; 1998. 479-483.

Koeppen M B, Stanton A B. Berne and Levy physiology, sixth edition. Philadelphia, PA: Mosby/Elsevier; 2008. 289-303

Serguei Semenov (2009): Lecture notes. Physiological measurements, ecg/pacemakers/defibrillators.

Cohen J B, Wood L D. Structure and function of the human body, seventh edition. Philadelphia: Lippincott Williams and Wilkins; 2000. 195-204.

Vandegriff K. D, Benazzi L, Ripamonti M, Perrella M, Tellier Le Y. C, Zegna A, Winslow R M. Determination of the rate and equilibrium constants for oxygen and carbon monoxide binding to R-state human Hemoglobin, 199: The journal of Biological Chemistry ; 266 (26): 17049-17059

Elaine N M, Katja H. Human anatomy and physiology, seventh edition. Menlo Park: Benjamin Cummings; 2007. 674-681

Sherwood L. Human physiology: from cells to systems, sixth edition. Belmont, CA: homson/Brooks/Cole; 2007. 300-304

Saladin K S. Anatomy and physiology: The unity of form and function, fifth edition. Maidenhead: McGraw-Hill Higher Education; 2009. 683-755

Stanfield C L, Germann W J, Niles J N, Cannon J G. Principles of human physiology, third edition. San Francisco: Pearson/Benjamin Cummings; 2009. 361-366

Skeletal Muscle

Question:

Describe the structure of skeletal muscle and how it contracts (90) and discuss a disease that may arise from this system (10)

The structure of skeletal muscle and the mechanism of muscle contraction including muscle disease (1553 Words)

1. 0 ABSTRACT

Skeletal Muscle is a form of fibrous tissue with the fibers arranged parallel to each other. A muscle fiber (cell) is surrounded by the endomysium. A group of these cells is wrapped by fascicles. Bundles of fascicles are covered by the perimysium and bundles of the perimysium are wrapped by the epimysium to form a muscle. The muscle fibers have contractile properties which enable them to move “ bony levers in order to produce skeletal movement” 1. The functional unit of the muscle fiber is the sacomere which consists of most importantly, actin and myosin. The actin and myosin are arranged such that during contraction, they can slide over each other thus shortening the muscle2.

Muscles suffer from many diseases, one of which is polymyositis. This is an inflammatory myopathy that affects mainly the muscles of the thorax and those around the torso. It affects all age groups but has been noticed mainly in late childhood and early adulthood. The sypmtomps are nonspecific but results in general muscle weakness and the cause, though believed to be an invasion by the white blood cells, is not very clear10.

2. 0 The Structure of Skeletal Muscle.

In daily life, structures and arrangements of designs are dictated, to a large extent by the purpose and function for which the design is meant for. Knowing that skeletal muscle is made up mainly of fibrous tissues, the arrangement of these tissues and how they are bound together to maintain a particular shape in order to accomplish different purposes (mainly to generate force and produce movement) may to a large extent, define the structure of the muscle4.

At a macro level, the skeletal muscle is composed of bundles of individual muscle fibers, the supporting structure called the basal lamina, and the connective tissue sheaths as shown in figure 1. These connective tissues bind the cells together giving them strength and partly providing mechanical protection2. We can examine these connective tissues and their functions as follows:

2. 1 The basal lamina. This is an extracellular matrix that acts as a scaffold on which a cell sits. It has been realized that apart from providing structural support, the basal lamina can orient and constrain cell during the process of regeneartion3.

2. 2 The endomysium. This is a fine sheath of connective tissue that surrounds each individual muscle cell. The endomysium consist of loosely “ interlacing fibers composed mainly of collagen” 4.

2. 3 The perimysium and fascilces. The individual muscle fibers wrapped by the endomysium, are grouped together in what is called fascicles. A layer of fibrous tissue called the perimysium wraps each fascicle4.

2. 4 The epimysium. This is the outside layer that finally wraps the whole muscle. It is composed of “ dense irregular connective tissue” 4.

Figure 1

Source: http://www. web-books. com/eLibrary/Medicine/Physiology/Muscular/muscle_structure. jpg

3. 0 The muscle cell

Having described how individual muscle cells are organized into a muscle, it is imperative that we look at the structural composition of the cell itself. Just like many other cells in the body are specialized according to their functions, skeletal muscle cells are specialized to produce force and movement5. The skeletal muscle fiber is thus composed of mainly three structural elements:- the myofibrils, the sarcoplasmic reticulum and the mitochondria, each contributing a unique aspect of muscle function. The entire function of the muscle can be attributed to the shifts in proportions of these three structures6.

3. 1 The Myofibrills. These are cylindrical specialized sub-units within the muscle fiber. They consist of two types of contractile protein filaments-the thin filaments referred to as actin and the thick filaments referred to as myosin. The two most important parameters of the myofibrils are their diameter which determines its strength and the fiber length which determines it contraction velocity and distance over which the fiber can contract. The myofibril consist of two filaments-actin and myosin6, 2.

3. 1. 1 Actin (thin filament). Actin filaments are responsible for regulation of contraction. The actin filament is formed by a “ helical arranged of actin monomers which is an ambiguous protein” 2 (figure 2). Because of the helical nature, a long grove is formed along the filament and the protein troponin is located at intervals along the length of the actin filament. It is troponin which is responsible for turning on contraction2, 7.

Figure 2. The actin molecule. Source: http://www. ucl. ac. uk/~sjjgsca/Muscleslidingfilament1. gif

3. 1. 2 The Myosin (thick filament). Myosin filament is about 150nm long. It has a tail and two heads. The tail is formed by two helical shaped fibers that coil around each other. A collection of several of these helical tails together form a myosin filament (figure 3)4b.

Figure 3. The myosin molecule. Source: http://webanatomy. net/anatomy/myosin. jpg.

3. 2 The sarcoplasmic reticulum (SR). “ Groups of about 200 thick and thin filaments constitute a myofibril”. Each myofibril is thus enclosed in a membrane called the sarcoplasmic reticulum8. The SR membrane stores and releases calcium during muscle contraction and relaxation. The SR can therefore be thought of as the functional unit of the myofibril9.

3. 3 The mitochondria. Found within the cell cytoplasm, the mitochondria are responsible for generation of most of the cell’s energy by the production of adenosine triphosphate (ATP). There are several mitochondria distributed along the length of a myofibril4.

4. 0 The mechanism of muscle contraction

Muscle contraction can largely be attributed to the structure of actin and myosin, their arrangement within the SR and the interaction between them in order to produce force (Figure 4). This type of arrangement allows the thin actin filaments to slide in and out by the action pull of the myosin heads8b.

Figure 4. Actin and myosin arrangement: Source: http://www. exrx. net/Images/ActinMyosin. gif

Muscles are composed of a number of actin and myosin filaments arranged in series in a basic unit called the sacomere. The sacomere consists of a thick filament in the meddle and two thin filaments, one overlapping on each side. The heads of the thick filament attach to the thin filament at the overlap and these heads allow movement in only one direction. When activated, each thick filament head “ rachets” repeatedly along the actin, pulling the two actins closer together.

Since the actin are attached to the Z line (The distance between two Z lines form the sacomere), ends of the sacomere (Z lines) are pulled in and the sacomere shortens. The sacomeres are arranged in series so that when the muscle fiber contracts, all the sacomeres contract simultaneously transmitting the force to the end of the muscle. The whole process of contraction described above occurs when the muscle is “ electrically” stimulated2b.

5. 0 Muscle stimulation.

“ Skeletal muscle cells are stimulated by the motor neurons of the somatic nervous system”. The reception of the motor stimulus (action potential)

opens the calcium channels allowing calcium which is stored in the SR to be released. The release of calcium causes the release of acetylcholine-Ach (neurotransmitter). The calcium binds to the troponin on the actin filament. Troponin then regulates the tropomyosin which obstructs binding sites for myosin. This allows the tropomyosin to move, unblocking the bonding site. Myosin then binds to the unblocked site on the actin and applies a pull. This will pull the Z bands towards each other thus shortening the sacomere, causing muscle contraction2b.

However, as calcium is released, the “ ATP-dependent calcium pump is activated” and it continuously pumps calcium back to the SR to be stored again. This leads to a drop in calcium level within the cytoplasm. When the calcium level is too low, the calcium binding action to troponin is terminated, releasing tropomyosin which again blocks the binding site. This stops the interaction between actin and myosin thus relaxing the muscle2b.

6. 0 Muscle Diseases

There are a number of muscular diseases and disorders ranging from acquired, familial to congenital. Limiting ourselves to one of the acquired disorders of the muscles, let’s look at polymyositis.

6. 1 Polymyositis (PM).

PM is a type of muscle inflammatory myopathy. Just like the name suggests, this disease causes inflammation of the muscle fiber. Although the causes of the disease are not well understood, it is believed that PM begins when white blood cells, spontaneously invade muscles. This can result in severe muscle weakness. Polymyositis is a persistent disease characterized by periods of

increased and reduced or no symptoms. PM affects mainly the muscles of the thorax and is more common in women than men. It is said to affect all age groups although is it commonly noted in early childhood or 20s10.

Key pathologic and diagnostic features of the disease.

Endomysial inflammation. This is the inflammation of the outer connective tissue that surrounds the muscle fiber. This is done by the white blood cells that leave the blood and enter the tissue, somehow confirming the earlier assertion that the PM begins when white blood cells invade muscles.

Invasion of myofibers by autoaggressive lymphocytes. This is when the T lymphocytes begin to attack the intact myofibers. Unlike in muscle dystrophy where inflammation is associated with degenerating myofibers, the invasion of T lymphocytes causes inflammation of health myofibers in PM. This causes inflammation of healthy myofibers.

Other diagnostic features that may not be exactly specific to PM include “ myofiber necrosis, myophagocytosis, myofiber atrophy and fibrosis”, a feature of chronic PM10, 11.

7. 0 Conclusion

Human movement is only possible because of the action of muscle contraction. Voluntary contraction of muscle is made possible by the somatic nervous system which sends out an action potential activating the contraction process. The process is accomplished by the sliding of myosin and actin over each other.

Many diseases and disorders affect muscles, prominent among them is muscular polymyosis which causes inflammation of the muscles mainly around the torso. It’s believed to be caused by the unwanted action of the white blood cells and the symptoms include muscle weakness.