**Lecture topic is…**

**(Slide 1) Lecture 6**

**Physiology of blood circulation. Part 1**

**(Slide 2)** Lecture plan:

1. Heart muscle properties.
2. Cardiac cycle.
3. Electrocardiogram and its clinical significance.

**(Slide 3) The Heart and Circulatory System. Video**

**(Slide 4)** The human heart consists of four chambers: The left side and the right side each have one atrium and one ventricle. Each of the upper chambers, the right atrium (plural = atria) and the left atrium, act as receiving chambers and contract to push blood into the lower chambers, the right ventricle and the left ventricle. The ventricles serve as the primary pumping chambers of the heart, propelling blood to the lungs or to the rest of the body.

**(Slide 5)** There are two distinct but linked circuits in the human circulation called the pulmonary and systemic circuits. Although both circuits transport blood and everything it carries, we can initially view the circuits from the point of view of gases. The pulmonary circuit transports blood to and from the lungs, where it picks up oxygen and delivers carbon dioxide for exhalation. The systemic circuit transports oxygenated blood to virtually all of the tissues of the body and returns relatively deoxygenated blood and carbon dioxide to the heart to be sent back to the pulmonary circulation. These two circulations function simultaneously and thus the heart functions as a dual pump.

**(Slide 6)** The right ventricle pumps deoxygenated blood into the pulmonary trunk, which leads toward the lungs and bifurcates into the left and right pulmonary arteries. These vessels in turn branch many times before reaching the pulmonary capillaries, where gas exchange occurs: Carbon dioxide exits the blood and oxygen enters. The pulmonary trunk arteries and their branches are the only arteries in the post-natal body that carry relatively deoxygenated blood. Highly oxygenated blood returning from the pulmonary capillaries in the lungs passes through a series of vessels that join together to form the pulmonary veins − the only post-natal veins in the body that carry highly oxygenated blood. The pulmonary veins conduct blood into the left atrium, which pumps the blood into the left ventricle, which in turn pumps oxygenated blood into the aorta and on to the many branches of the systemic circuit. Eventually, these vessels will lead to the systemic capillaries, where exchange with the tissue fluid and cells of the body occurs. In this case, oxygen and nutrients exit the systemic capillaries to be used by the cells in their metabolic processes, and carbon dioxide and waste products will enter the blood.

**(Slide 7)** The blood exiting the systemic capillaries is lower in oxygen concentration than when it entered. The capillaries will ultimately unite to form venules, joining to form ever-larger veins, eventually flowing into the two major systemic veins, the superior vena cava and the inferior vena cava, which return blood to the right atrium. The blood in the superior and inferior venae cavae flows into the right atrium, which pumps blood into the right ventricle. This process of blood circulation continues as long as the individual remains alive. Understanding the flow of blood through the pulmonary and systemic circuits is critical to all health professions.

**(Slide 8)** Each cardiac myocyte is surrounded by a cell membrane called the sarcolemma and contains one nucleus. The cells are packed with mitochondria to provide the steady supply of ATP required to sustain cardiac contraction. As with skeletal muscle, cardiac myocytes contain the contractile proteins actin (thin filaments) and myosin (thick filaments) together with the regulatory proteins troponin and tropomyosin. Cardiac muscle is striated, although the pattern is not as ordered as in skeletal muscle.

**Slide 9** shows the arrangement of the thick and thin filaments. The myofilaments within the myocyte are surrounded by sleeves of sarcoplasmic reticulum, analogous to endoplasmic reticulum found in other cells. Separate tubular structures, the transverse tubules (T tubules), cross the cell. In the cardiac myocyte, the T tubule crosses at the Z-line, in contrast to the A-I junction in skeletal muscle. The lumen of the T tubule is continuous with the extracellular fluid surrounding the cell and, as in skeletal muscle, the action potential is propagated down the T tubule. Adjacent cardiac myocytes are joined end-to-end at structures known as intercalated disks. These always occur at a Z-line. At these points, the cell membranes form a number of parallel folds and are tightly held together by desmosomes. This results in strong cell-to-cell cohesion, thus allowing the contraction of one myocyte to be transmitted axially to the next. Gap junctions exist between cardiac muscle cells, providing low resistance pathways for the spread of excitation from one cell to another. Mitochondria are plentiful, providing energy for the contractions of the heart. Typically, cardiomyocytes have a single, central nucleus, but two or more nuclei may be found in some cells.

**(Slide 10) Cardiac Muscle Physiology. Video**

**(Slide 11)** Recall that cardiac muscle shares a few characteristics with both skeletal muscle and smooth muscle, but it has some unique properties of its own. Contractions of the heart (heartbeats) are controlled by specialized cardiac muscle cells called pacemaker cells that directly control heart rate. This property is known as autorhythmicity. Neither smooth nor skeletal muscle can do this. Although cardiac muscle cannot be consciously controlled, the pacemaker cells respond to signals from the autonomic nervous system (ANS) to speed up or slow down the heart rate. The pacemaker cells can also respond to various hormones that modulate heart rate to control blood pressure.

**(Slide 12) How the Heart Works Video.**

**(Slide 13)** The cardiac action potential is very different to that seen in nerves. It has a prolonged plateau phase lasting around 300 ms compared with 1 ms in nerves. The cardiac action potential has five phases as shown in Slide. During phase 0, membrane permeability to potassium decreases and fast sodium channels open, producing rapid depolarization from −90 mV to +10 mV. During phase 1, there is partial repolarization, because of a decrease in sodium permeability. Phase 2 is the plateau phase of the cardiac action potential. Membrane permeability to calcium increases during this phase, maintaining depolarization and prolonging the action potential. Membrane permeability to calcium decreases somewhat towards the end of phase 2, and the plateau is partially maintained by an inward sodium current. Sodium flows into the cell through the sodium–calcium exchanger. The exchanger transfers three sodium ions into the cell in exchange for one calcium ion flowing out, and so produces a net inward positive current. As calcium channels inactivate towards the end of the plateau phase, an inward potassium current produces repolarization in phase 3. The resting membrane potential in phase 4 is approximately −90 mV. This is produced mainly by the selective permeability of the cell membrane to potassium and the concentration gradient for potassium that exists across the cell membrane and is close to the Nernst equilibrium potential for potassium.

**(Slide 14)** Much of the calcium influx in the plateau phase occurs through L-type (long opening) calcium channels. Increased activation of L-type channels occurs with catecholamine exposure, whilst they are blocked by calcium channel antagonists such as verapamil. The cardiac action potential lasts about 300 ms. For the vast majority of this time, the cell is absolutely refractory to further stimulation. In other words, a further action potential will not be generated until repolarization is virtually complete. This prevents tetany from occurring. If a supramaximal stimulus occurs during the relative refractory period, the resultant action potential has a slower rate of depolarization and is of smaller amplitude than normal, producing a much weaker contraction than normal.

**(Slide 15)** There are two major types of cardiac muscle cells: myocardial contractile cells and myocardial conducting cells. The myocardial contractile cells constitute the bulk (99 percent) of the cells in the atria and ventricles. Contractile cells conduct impulses and are responsible for contractions that pump blood through the body. The myocardial conducting cells (1 percent of the cells) are the autorhythmic cells and form the conduction system of the heart. Except for Purkinje cells, they are generally much smaller than the contractile cells and have few of the myofibrils or filaments needed for contraction. Their function is similar in many respects to neurons, although they are specialized muscle cells. Myocardial conduction cells initiate and propagate the action potential (the electrical impulse) that travels throughout the heart muscle and triggers the contractions that propel the blood.

**(Slide 16)** Cardiac muscle cells branch freely. A junction between two adjoining cells is marked by a critical structure called an intercalated disc, which helps support the synchronized contraction of the muscle (Slide 16 b). The sarcolemmas from adjacent cells bind together at the intercalated discs. They consist of desmosomes, specialized linking proteoglycans, tight junctions, and large numbers of gap junctions that allow the passage of ions between the cells and help to synchronize the contraction (Slide 16 c). Intercellular connective tissue also helps to bind the cells together. The importance of strongly binding these cells together is necessitated by the forces exerted by contraction.

As shown in **Slide 17**, it differs from the action potential of cardiac myocytes in that phases 1 and 2 are absent. The heart displays autorhythmicity: a denervated heart (such as the heart of a cardiac transplant patient) continues to contract spontaneously. Pacemaker cells do not have a stable resting action potential, and it is the spontaneous depolarization of the pacemaker potential that gives the heart its auto-rhythmicity. The pacemaker potential is produced by a decrease in membrane permeability to potassium, a slow inward current because of calcium influx via T-type (transient) calcium channels, and an increased sodium current because of sodium–calcium exchange. Once the threshold potential is reached, L-type calcium channels open, calcium ions enter the cell, and depolarization occurs. In contrast to the cardiac myocyte action potential, there is no inward movement of sodium ions during depolarization. Repolarization (phase 3 of the action potential) occurs because of an increase in potassium permeability. At the sinoatrial node, potassium permeability can be further enhanced by vagal stimulation. This has the effect of hyperpolarizing the cell and reducing the rate of firing. Sympathetic stimulation has the opposite effect.

**(Slide 18) Pacemaker Action Potential. Video**

**(Slide 19)** The period of timethat begins with contraction of the atria and ends with ventricular relaxation is known as the cardiac cycle. The period of contraction that the heart undergoes while it pumps blood into circulation is called systole. The period of relaxation that occurs as the chambers fill with blood is called diastole. Both the atria and ventricles undergo systole and diastole, and it is essential that these components be carefully regulated and coordinated to ensure blood is pumped efficiently to the body.

**(Slide 20)** Fluids, whether gases or liquids, are materials that flow according to pressure gradients − that is, they move from regions that are higher in pressure to regions that are lower in pressure. Accordingly, when the heart chambers are relaxed (diastole), blood will flow into the atria from the veins, which are higher in pressure. As blood flows into the atria, the pressure will rise, so the blood will initially move passively from the atria into the ventricles. When the action potential triggers the muscles in the atria to contract (atrial systole), the pressure within the atria rises further, pumping blood into the ventricles. During ventricular systole, pressure rises in the ventricles, pumping blood into the pulmonary trunk from the right ventricle and into the aorta from the left ventricle. Again, as you consider this flow and relate it to the conduction pathway, the elegance of the system should become apparent.

**(Slide 21)** At the beginning of the cardiac cycle, both the atria and ventricles are relaxed (diastole). Blood is flowing into the right atrium from the superior and inferior venae cavae and the coronary sinus. Blood flows into the left atrium from the four pulmonary veins. The two atrioventricular valves, the tricuspid and mitral valves, are both open, so blood flows unimpeded from the atria and into the ventricles. Approximately 70–80 percent of ventricular filling occurs by this method. The two semilunar valves, the pulmonary and aortic valves, are closed, preventing backflow of blood into the right and left ventricles from the pulmonary trunk on the right and the aorta on the left.

**(Slide 22)** Contraction of the atria follows depolarization, represented by the P wave of the ECG. As the atrial muscles contract from the superior portion of the atria toward the atrioventricular septum, pressure rises within the atria and blood is pumped into the ventricles through the open atrioventricular (tricuspid, and mitral or bicuspid) valves. At the start of atrial systole, the ventricles are normally filled with approximately 70–80 percent of their capacity due to inflow during diastole. Atrial contraction, also referred to as the “atrial kick,” contributes the remaining 20–30 percent of filling. Atrial systole lasts approximately 100 ms and ends prior to ventricular systole, as the atrial muscle returns to diastole.

**(Slide 23)** Ventricular systole follows the depolarization of the ventricles and is represented by the QRS complex in the ECG. It may be conveniently divided into two phases, lasting a total of 270 ms. At the end of atrial systole and just prior to atrial contraction, the ventricles contain approximately 130 mL blood in a resting adult in a standing position. This volume is known as the end diastolic volume (EDV) or preload.

**(Slide 24)** Initially, as the muscles in the ventricle contract, the pressure of the blood within the chamber rises, but it is not yet high enough to open the semilunar (pulmonary and aortic) valves and be ejected from the heart. However, blood pressure quickly rises above that of the atria that are now relaxed and in diastole. This increase in pressure causes blood to flow back toward the atria, closing the tricuspid and mitral valves. Since blood is not being ejected from the ventricles at this early stage, the volume of blood within the chamber remains constant. Consequently, this initial phase of ventricular systole is known as isovolumic contraction, also called isovolumetric contraction.

**(Slide 25)** In the second phase of ventricular systole, the ventricular ejection phase, the contraction of the ventricular muscle has raised the pressure within the ventricle to the point that it is greater than the pressures in the pulmonary trunk and the aorta. Blood is pumped from the heart, pushing open the pulmonary and aortic semilunar valves. Pressure generated by the left ventricle will be appreciably greater than the pressure generated by the right ventricle, since the existing pressure in the aorta will be so much higher. Nevertheless, both ventricles pump the same amount of blood. This quantity is referred to as stroke volume.

**(Slide 26)** Stroke volume will normally be in the range of 70–80 mL. Since ventricular systole began with an end diastolic volume of approximately 130 mL of blood, this means that there is still 50–60 mL of blood remaining in the ventricle following contraction. This volume of blood is known as the end systolic volume (ESV).

**(Slide 27)** Ventricular relaxation, or diastole, follows repolarization of the ventricles and is represented by the T wave of the ECG. It too is divided into two distinct phases and lasts approximately 430 ms. During the early phase of ventricular diastole, as the ventricular muscle relaxes, pressure on the remaining blood within the ventricle begins to fall. When pressure within the ventricles drops below pressure in both the pulmonary trunk and aorta, blood flows back toward the heart, producing the dicrotic notch (small dip) seen in blood pressure tracings. The semilunar valves close to prevent backflow into the heart. Since the atrioventricular valves remain closed at this point, there is no change in the volume of blood in the ventricle, so the early phase of ventricular diastole is called the isovolumic ventricular relaxation phase, also called isovolumetric ventricular relaxation phase.

In the second phase of ventricular diastole, called late ventricular diastole, as the ventricular muscle relaxes, pressure on the blood within the ventricles drops even further. Eventually, it drops below the pressure in the atria. When this occurs, blood flows from the atria into the ventricles, pushing open the tricuspid and mitral valves. As pressure drops within the ventricles, blood flows from the major veins into the relaxed atria and from there into the ventricles. Both chambers are in diastole, the atrioventricular valves are open, and the semilunar valves remain closed. The cardiac cycle is complete.

**(Slide 28) The Cardiac Cycle Animation. Video**

**(Slide 29)** Cardiac output (CO) is a measurement of the amount of blood pumped by each ventricle in one minute. To calculate this value, multiply stroke volume (SV), the amount of blood pumped by each ventricle, by heart rate (HR), in contractions per minute (or beats per minute, bpm). It can be represented mathematically by the following equation:

CO = HR × SV

**(Slide 30)** SV is normally measured using an echocardiogram to record EDV and ESV, and calculating the difference: SV = EDV – ESV. SV can also be measured using a specialized catheter, but this is an invasive procedure and far more dangerous to the patient. A mean SV for a resting 70-kg (150-lb) individual would be approximately 70 mL. Normal range for SV would be 55–100 mL. An average resting HR would be approximately 75 bpm but could range from 60–100 in some individuals. There are several important variables, including size of the heart, physical and mental condition (via hormones and the ANS) of the individual, gender, contractility, duration of contraction, preload or EDV, and afterload or resistance that cn effect SV and HR.

**(Slide 31)** Using these numbers, the mean CO is 5.25 L/min, with a range of 4.0–8.0 L/min. Remember, however, that these numbers refer to CO from each ventricle separately, not the total for the heart. In a healthy heart the CO from each ventricle is the same. Factors influencing CO are summarized in the Slide. Stroke volumes are also used to calculate ejection fraction, which is the portion of the blood that is pumped or ejected from the heart with each contraction. To calculate ejection fraction, stroke volume is divided by EDV. Despite the name, the ejection fraction is normally expressed as a percentage. Ejection fractions range from approximately 55–70 percent, with a mean of 58 percent.

**(Slide 32)** In healthy young individuals, HR may increase to 150 bpm or higher during exercise. Stroke volume can also increase from 70 to approximately 130 mL due to increased strength of contraction. This would increase CO to approximately 19.5 L/min, 4–5 times the resting rate. Top cardiovascular athletes can achieve even higher levels. At their peak performance, they may increase resting CO by 7–8 times. Since the heart is a muscle, exercising it increases its efficiency. The difference between maximum and resting CO is known as the cardiac reserve. It measures the residual capacity of the heart to pump blood.

**(Slide 33)** By careful placement of surface electrodes on the body, it is possible to record the complex, composite electrical signal of the heart. This tracing of the electrical signal is the electrocardiogram (ECG), also commonly abbreviated EKG (K coming kardiology, from the German term for cardiology). Careful analysis of the ECG reveals a detailed picture of both normal and abnormal heart function, and is an indispensable clinical diagnostic tool. The standard electrocardiograph (the instrument that generates an ECG) uses 3, 5, or 12 leads. The greater the number of leads an electrocardiograph uses, the more information the ECG provides. The term “lead” may be used to refer to the cable from the electrode to the electrical recorder, but it typically describes the voltage difference between two electrodes (bipolar leads). The 12-lead electrocardiograph uses 10 electrodes placed in standard locations on the patient’s skin, the chest electrodes are unipolar and the appendage leads are bipolar.

**(Slide 34)** In continuous ambulatory electrocardiographs, the patient wears a small, portable, battery-operated device known as a Holter monitor, or simply a Holter, that continuously monitors heart electrical activity, typically for a period of 24 hours during the patient’s normal routine.

**(Slide 35)** A normal ECG tracing is presented **in the Slide**. Each component, segment, and interval is labeled and corresponds to important electrical events, demonstrating the relationship between these events and contraction in the heart. There are five prominent components (points) on the ECG: the P wave, the QRS complex, and the T wave. The small P wave represents the depolarization of the atria. The atria begin contracting approximately 25 ms after the start of the P wave. The large QRS complex represents the depolarization of the ventricles, which requires a much stronger electrical signal because of the larger size of the ventricular cardiac muscle. The ventricles begin to contract as the QRS reaches the peak of the R wave. Lastly, the T wave represents the repolarization of the ventricles. The repolarization of the atria occurs during the QRS complex, which masks it on an ECG.

**(Slide 36)** Segments are defined as the regions between two waves. Intervals include one segment plus one or more waves. For example, the PR segment begins at the end of the P wave and ends at the beginning of the QRS complex. The PR interval starts at the beginning of the P wave and ends with the beginning of the QRS complex. The PR interval is more clinically relevant, as it measures the duration from the beginning of atrial depolarization (the P wave) to the initiation of the QRS complex. Since the Q wave may be difficult to view in some tracings, the measurement is often extended to the R that is more easily visible. Should there be a delay in passage of the impulse from the SA node to the AV node, it would be visible in the PR interval.

**(Slide 37)** One of the simplest, yet effective, diagnostic techniques applied to assess the state of a patient’s heart is auscultation using a stethoscope. In a normal, healthy heart, there are only two audible heart sounds: S1 and S2. S1 is the sound created by the closing of the atrioventricular valves during ventricular contraction and is normally described as a “lub,” or first heart sound. The second heart sound, S2, is the sound of the closing of the semilunar valves during ventricular diastole and is described as a “dub”. In both cases, as the valves close, the openings within the atrioventricular septum guarded by the valves will become reduced, and blood flow through the opening will become more turbulent until the valves are fully closed. There is a third heart sound, S3, but it is rarely heard in healthy individuals. It may be the sound of blood flowing into the atria, or blood sloshing back and forth in the ventricle, or even tensing of the chordae tendineae. S3 may be heard in youth, some athletes, and pregnant women. If the sound is heard later in life, it may indicate congestive heart failure, warranting further tests. Some cardiologists refer to the collective S1, S2, and S3 sounds as the “Kentucky gallop,” because they mimic those produced by a galloping horse. The fourth heart sound, S4, results from the contraction of the atria pushing blood into a stiff or hypertrophic ventricle, indicating failure of the left ventricle. S4 occurs prior to S1 and the collective sounds S4, S1, and S2 are referred to by some cardiologists as the “Tennessee gallop,” because of their similarity to the sound produced by a galloping horse with a different gait. A few individuals may have both S3 and S4, and this combined sound is referred to as S7.

**(Slide 38)** The term murmur is used to describe an unusual sound coming from the heart that is caused by the turbulent flow of blood, usually due to valve problesms. For example an incompetent valve does not close completely leading to a “swish” sound as the blood flows backwards through the valve. A high pitch sound results as blood moves through a stiff (stenotic) valve. Murmurs are graded on a scale of 1 to 6, with 1 being the most common, the most difficult sound to detect, and the least serious. The most severe is a 6. Phonocardiograms or auscultograms can be used to record both normal and abnormal sounds using specialized electronic stethoscopes.

**(Slide 39)** During auscultation, it is common practice for the clinician to ask the patient to breathe deeply. This procedure not only allows for listening to airflow, but it may also amplify heart murmurs. Inhalation increases blood flow into the right side of the heart and may increase the amplitude of right-sided heart murmurs. Expiration partially restricts blood flow into the left side of the heart and may amplify left-sided heart murmurs. Slide indicates proper placement of the bell of the stethoscope to facilitate auscultation.

**(Slide 40) Heart murmur sounds (cardiac auscultation sounds). Video**

**(Slide 41)** The cardiac cycle comprises a complete relaxation and contraction of both the atria and ventricles, and lasts approximately 0.8 seconds. Beginning with all chambers in diastole, blood flows passively from the veins into the atria and past the atrioventricular valves into the ventricles. The atria begin to contract (atrial systole), following depolarization of the atria, and pump blood into the ventricles. The ventricles begin to contract (ventricular systole), raising pressure within the ventricles. When ventricular pressure rises above the pressure in the atria, blood flows toward the atria, producing the first heart sound, S1 or lub. As pressure in the ventricles rises above two major arteries, blood pushes open the two semilunar valves and moves into the pulmonary trunk and aorta in the ventricular ejection phase. Following ventricular repolarization, the ventricles begin to relax (ventricular diastole), and pressure within the ventricles drops. As ventricular pressure drops, there is a tendency for blood to flow back into the atria from the major arteries, producing the dicrotic notch in the ECG and closing the two semilunar valves. The second heart sound, S2 or dub, occurs when the semilunar valves close. When the pressure falls below that of the atria, blood moves from the atria into the ventricles, opening the atrioventricular valves and marking one complete heart cycle. The valves prevent backflow of blood. Failure of the valves to operate properly produces turbulent blood flow within the heart; the resulting heart murmur can often be heard with a stethoscope.

Finish for today

The full lecture is at the indicated website.

**Thank you for attention**