BASIC SCIENCE OF OBSTETRICS AND GYNAECOLOGY FOR POSTGRADUATES

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CARDIOVASCULAR CHANGES IN PREGNANCY

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INTRODUCTION

Cardiovascular system (CVS) is vital to sustaining the metabolism and functionality of the whole body in most animals including mammals. It is a closed tubular system that functions as a unit, and it is often described as a "hydraulic system". CVS comprises of the "Cardio" – which was derived from Greek word "Kardia" meaning heart, and the "Vascular" – derived from *'having vessels or ducts'. The* component parts of the system are: The heart, blood vessels and blood. The CVS is primarily responsible for the pumping and circulation of blood to all organs in the body including its component parts that form the cardiovascular system itself. This is why the system is also referred as the circulatory system. This system therefore ensures transport of oxygen and other essential nutrients to the cells of the body and at the same time remove carbon dioxide and other waste products from the body. In addition, the CVS is also actively involved in the transport of nutrients and removal of wastes of the developing fetus within the pregnant woman.

EMBRYOLOGICAL DEVELOPMENT

The CVS is largely a messenchymal derivative that starts to develop from the third week of intrauterine life. Though, the system is initially bilateral and symmetrical in structure but, it later fuses to become asymmetrical in shape. The heart beats and circulation of blood within the vessels starts functioning at the fourth week of intrauterine life. This makes CVS the first functional system in humans, however, it continues to mature with fetal age advancement till the fetus is delivered. Doppler ultrasound can detect embryonic heart beat by the 5^{th} week gestation, or 7^{th} weeks after the last menstrual period. The functionality of fetal CVS is limited in utero because of the overriding role of uteroplacental circulation which determines the exchange of oxygen and other nutrients supply from the maternal blood system into the fetal circulation. The termination of this role by the placenta after the baby is born is intrinsically modified in the fetal circulation and this results in some structural adaptation of the heart and blood vessels of the newborn. Similarly, CVS adaptation also varies with the prevailing mechanics of the body such as activity, pregnancy, drugs and so on. These will be discussed shortly. Furthermore, the haemopoietic system also starts developing by the third week of intrauterine life and transits through various developments involving the liver, spleen and eventually, the bone marrow becomes the primary site. It is important to note that any structural malformation during the embryological development could affect the function of the CVS and this is most common in the heart. This form of abnormality is referred to as congenital malformation of the heart.

SUMMARY OF CVS ANATOMY

The organs that principally forms the CVS are:

- The heart
- The blood vessels
- The blood cells and plasma volume

THE HEART

An adult female heart is globular, 'closed fist-size' organ located within the middle mediastinum, and enclosed in a double thin elastic membranous sheath called visceral and

parietal pericardium. The heart operates as a pump with four chambers: right atrium (RA), right ventricle (RV), left atrium (LA) and left ventricle (LV). The heart has 4 valves that ensure unidirectional flow of the circulation within its chambers. On the left half of the heart, the mitral valve is between the LA and LV while the aortic valve is between the LV and the aorta. On the right half, the tricuspid valve is between the RA and RV while the pulmonary valve is between the RV and PA. The heart is rotated so that the right ventricle and atrium form the greater part of anterior surface. The superior border of the heart is formed by the upper margin of the atria and it is covered by the ascending aorta and the pulmonary trunk (extends from left 2nd intercostal space to the right side of the sternum at the same level). The right border extends from the superior border to the right 6th intercostals cartilage and it is formed mainly by right atrium. The inferior border extends from the lowermost part of the right border on the 5th left intercostals space and it is principally formed by the right ventricle. The left border is convex and it is mostly formed by left ventricle. The diaphragmatic surface is formed by the ventricle, and the base which is often referred to as posterior or vertebra surface is formed by the atria. The blood supply to the heart itself is through the right and left coronary arteries anastomosis while the venous drainage is via cardiac veins (great, middle and small). The nerve supply to the heart is through autonomic nervous system. The sympathetic fibres (cervico-thoracic) stimulation causes increase in heart rate and cardiac contractility. It also dilates the coronary arteries. The parasympathetic (vagus nerve) is inhibitory to the heart. The nervous supply is modulated by baroreceptor mechanism.

THE BLOOD VESSELS

The blood vessels serve as the conduit to the rest of the body. They are thick walled with circular smooth muscles beneath the endothelium. This muscle absorbs the pressure waves of the heart beat and this can be palpated anywhere there is fairly large vessel wall as pulse. All arteries in the body receive blood that is pumped out of the heart through the aorta and this is transported via the arterioles to the capillaries – this is where the exchange function occurs at the tissue level The name of each of these arteries is largely a reflection of the organ it supplies or where it is located. The venules and veins (small and great) return blood back to the heart.

THE BLOOD CELLS AND PLASMA VOLUME

The blood cells (Red blood cells, Neutrophils, Eosinophils, Lymphocyte and platelets) and plasma (serum and clotting factors) constitute 'the passenger' of the cardiovascular system. The plasma volume of an adult non-pregnant woman is about 3500mls and the overall blood volume is about 5.0L

SUMMARY OF CVS PHYSIOLOGY

Understanding the basic physiology of the CVS physiology of an adult non-pregnant woman is critical to appreciating the changes that is associated with pregnancy state. The pumping action of the heart is normally initiated by the conducting system (sino-atrial node) consists of 2 phases – the diastole and systole. During the diastole, each ventricle fills and the atria contracts while, in systole, the ventricle contract and the atria are relaxed and fills with blood.

THE HEART RATE

This refers to each pumping action of the heart and heart rate is defined as the number of heart beats per minute. In a relaxed adult non-pregnant woman, the normal heart rate is between 60 to 100 beats per minute.

THE HEART SOUNDS

This is normally heard during cardiac auscultation, and it is normally depicted as first (S1) and second (S2) heart sounds. The S1 is due to closure of tricuspid and mitral valves and it occurs near the beginning of the systole whereas, the S2 occur near the end of the systole and it is due to closure of pulmonary and aortic valves. Abnormality of the valves (stenosis or incompetence) will result in abnormal heart sounds and the causes could be physiological such as pregnancy or pathological (rheumatic heart disease).

THE BLOOD PRESSURE

Blood pressure is the product of cardiac output and stroke volume. The cardiac output is the output of the heart per unit time while the stroke volume is the amount of blood pumped out of the each ventricle per beat. The cardiac output is a product of heart rate and stroke volume, and both increase in pregnancy. The changes in the peripheral vascular resistance have direct effect on cardiac output and invariably, it affects the blood pressure. Normal cardiac output in a non-pregnant adult female is ranged between 3.5 and 6.0L/minute.

THE PULSE RATES

This is usually evaluated by palpating the peripheral pulse especially radial artery is used. The normal arterial pulse is between 60 and 100 beats per minute in a non-pregnant adult

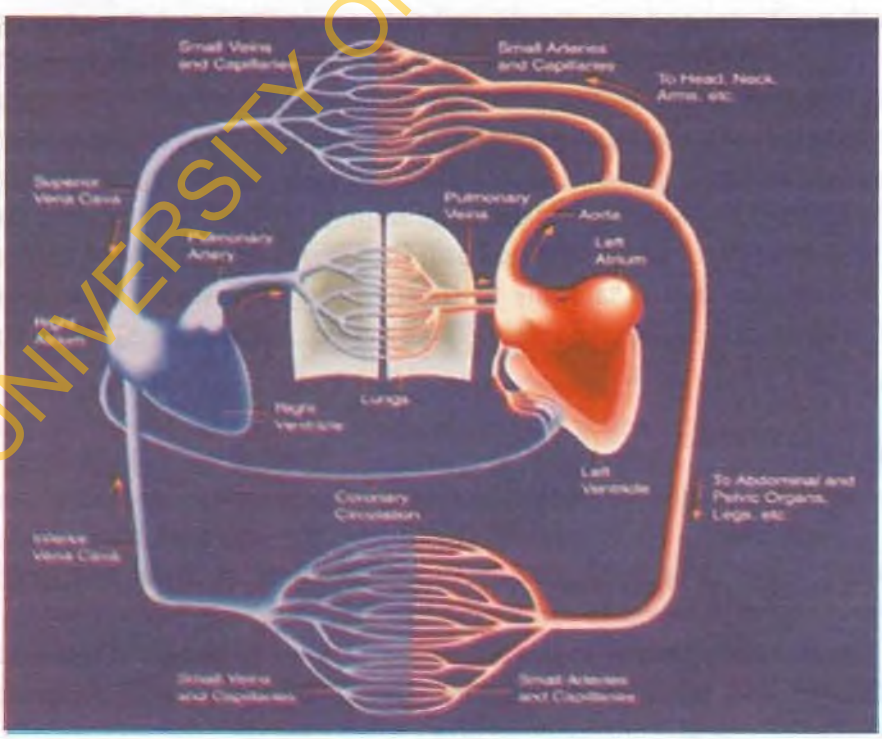

Figure 26.1: The annotated diagram of cardiovascular system physiology

THE PHYSIOLOGICAL FUNCTIONS: In adult, there are three broad functions of the CVS and they include;

Transportation of nutrients, oxygen and hormones to cells throughout the body and at the same time, it also play a significant role in the removal of metabolic waste products (carbon dioxide, nitrogenous wastes and heat) and other toxins in the body

It is involved in host defense mechanism with white blood cells, antibodies, and other components of the immune system that circulate in the blood and defend the body against foreign organism. The clotting mechanisms also protect the body from excessive bleeding after injuries.

Regulation of body temperature, Fluid pH and water content of the cells in the body.

THE CARDIOVASCULAR CHANGES IN PREGNANCY

The anatomic and physiological changes that develop during pregnancy and delivery are due to the following reasons: First, the increased metabolic demands from the pregnant woman, the growing fetus, placenta and uterus. Second, the increase elaboration of pregnancy hormones (oestrogen and progesterone) and lastly, the mechanical effect of the gravid uterus that impinges on the diaphragm and major abdominal vessels.

The changes observed will be discussed as anatomical and physiological changes to better appreciate the levels of the alterations. Please note that these changes occur simultaneously.

THE ANATOMIC CVS CHANGES

The observed changes are as follows:

THE HEART

There are both positional and structural (size) changes in the heart during pregnancy. The heart is enlarged and this is mainly due to dilation of the four chambers and hypertrophy of its muscle wall. The chamber dilation could result in valvular regurgitation especially the tricuspid. On radiological x-ray, there might be a slight increase of cardiothoracic ratio (normal is 0.5). There could also be a mild pericardial effusion which could increase the cardiothoracic ratio too. The upward displacement of the diaphragm as a result of the gravid uterus causes the heart to be displaced to the left and upward. This causes rotation along its long axis, thus, making the apex to be shifted laterally to the non-pregnant state. These heart changes represented on electrocardiography as left axis deviation, sagging ST segments and inversion or flattening of the T wave in lead III.

THE BLOOD VESSELS

The blood vessels become dilated due to the smooth muscle relaxant effect of progesterone, prostacyclin (vasodilator) – increased level reduces the vascular tone, and endothelin (vasoconstrictor) – increase level initiate the production of atrial natriuretic peptide, aldosterone and catecholamines to reduce cardiac output in pregnancy. The loss of vascular reactivity of the vessels especially in the arteries in pregnancy results in reduced peripheral vascular resistance and blood pressure. The dilation of the vessels, reduced reactivity, increased blood volume and reduced blood flow causes their distension especially the venous vessels. Another factor that is responsible for the loss of vascular tone in pregnancy is the

second wave of trophoblastic invasion of the blood vessel wall to replace the smooth muscle wall. Failure of this occurring has been documented in preeclamptic/eclamptic women. The refractoriness of the vascular tone in pregnancy is lost within half an hour after delivery of the placenta suggesting the role placenta plays in the aetio-pathogenesis of preeclampsia/eclampsia.

THE BLOOD

The red cell mass increase in pregnancy by 20 to 30 percent. The white cell and platelet counts are slightly elevated but usually within the upper limit of normal. The elevation is marked during the peripartal period. The plasma volume generally increases from the first trimester (from 6th week) and reaches a maximum level at 32 – 34 weeks. The increase of plasma volume (40-50%) is higher than the red cell mass resulting in physiologic anaemia in pregnancy which usually manifests in the second trimester. The degree of the anaemia is mainly dependent on the pre-pregnancy haematocrit level and number of index pregnancy.

THE PHYSIOLOGIC CHANGES OF CVS

The physiological changes that occur in pregnancy are in response to the changing demand by the current metabolic state and at the same time `prepare the prospective mother for parturition. Furthermore, the physiological changes occur in tandem to the anatomical or structural changes of the various organs that constitute the CVS.

THE HEART RATE (HR)

The heart rate begins to rise in pregnancy from the 5-6th week of gestation and the initial rise is due to the 'circulatory underfilling signals' that the heart experiences from the generalized peripheral dilation (falling systemic vascular resistance –SVR) but, the stroke volume is still within normal range. This signal mimics a hypovolemic state thus making the heart to respond by increasing its minute beats. With advancement in pregnancy, the increased blood volume also contributes to the heart rate up till parturition and few weeks in the puerperium. The heart rate increase is in the range of 10 to 15 beats per minute signifying about 10 to 20 percent change. The rapid heart rate reduces the diastolic filling time and ultimately, reduces the cardiac output.

HEART SOUNDS

In the first trimester, the first heart sound (S1) is louder and there may be splitting and towards term, the second heart sound (S2) becomes louder especially during expiration. Nine out of 10 pregnant women have S3 gallop after mid-pregnancy. Systolic ejection murmurs are present in over 95 percent of pregnant women along the left sternal border, and this is usually due to increase blood flow on across aortic and pulmonary valves. 'Mammary souffle' is also present on both sides of 2nd to 4th intercostals surface due to increased blow flow through the internal mammary vessels that supply the breast. Rarely is the fourth heart sound heard in a normal pregnant individual.

CARDIAC OUTPUT (CO)

Generally, the cardiac output increases by about 30 to 50 percent of the non-pregnant state and this change is noticeable from the first trimester till third trimester (plateau at 32 weeks). The increase in CO is a reflection of the degree of heart rate and stroke volume increase. In the

advanced pregnancy, **CO** is dependent on the position the pregnant woman adopts. CO is reduced in supine position, it is the same as pre-pregnancy state in standing position, and it is higher when left lateral position **is** adopted. The enlarged gravid uterus compresses the inferior vena cava, this reduces the venous return and ultimately the CO is reduced. CO has also been shown to increase with the number of pregnancies. CO also rises during labour and reduces after delivery reaching normal level by 18 to 24 weeks postpartum.

STROKE VOLUME (SV)

The stroke volume rises from the first trimester reaching a plateau at 16 to 20weeks. The increase is about 5 to 10ml per stroke above the normal non-pregnant state.

SYSTEMATIC VASCULAR RESISTANCE (SVR)

The fall in SVR observed in pregnancy from the first trimester reaches a nadir by 14 to 24 weeks and then rises towards the later part of the pregnancy. This fall is as a result of the generalized peripheral vasodilatation that is due to increased elaboration of progesterone and other vasodilating substances such as Nitric oxide. The reduced SVR in pregnancy mimics a 'circulatory underfill' contributing to the hyperdynamic circulation observed.

BLOOD PRESSURE (BP)

The changes in arterial blood pressure are more pronounced than the venous pressure. Regarding arterial blood pressure, there is a progressive fall in BP in the first 24-weeks (nadir) of pregnancy mainly due to generalized peripheral vasodilatation and thereafter, the BP rises and gradually returns to normal pre-pregnancy state. The fall in systolic BP is on the average of 5 – 10mmHg and the diastolic BP falls by 10 – 15mmHg before 24 weeks, thus, making the pulse pressure to increase. The hyperdynamic nature of the pregnancy makes BP measurement and reproducibility challenging. However, the current consensus is to use the Korotkoff 5 (When sound disappears completely) during auscultation for BP, as it is easier to measure and reproduce than the formerly advocated 4th Korotkoff sound (When sound becomes muffled).The venous blood pressure in the lower extremities increases in response to mechanical effect of the pregnancy and there are no significant changes in upper extremities venous pressure. The central venous pressure remains unchanged throughout the pregnancy.

OVERALL HAEMODYNAMIC CHANGES

The response of CVS to pregnancy, labour and delivery may be thought to be abnormal findings rather, it is meant to support the maternal physiology to cope with current demands. Most normal changes observed are key findings of CVS disorders in a non-pregnant woman. The increased heart rate (tachycardia), heart murmurs, and sometimes leg swelling (oedema) are typical signs of heart failure. It is therefore crucial to evaluate well to be able to differentiate between physiological or pathological findings.

Table 26.1: Summary of CVS changes in pregnancy

Parameters	Changes	Time during pregnancy
Heart rate	↑	First and Second trimester
Blood pressure	↓	Falls in first and second trimester, returns to normal in the third trimester
Cardiac output	↑	30 – 50% above normal by third trimester
Stroke volume	↑	It peaks at 16 – 20weeks
Systemic vascular resistance	↓	It reaches nadir at 14 – 24 weeks
Pulmonary vascular resistance	↓	Decreases by 20 – 30 %

SUPINE HYPOTENSION SYNDROME

This disorder is most common in pregnancy and it usually occurs in about 8-10percent of cases. It is also referred to as Aorto-caval syndrome. The cause is due to compression of the gravid uterus on the inferior vena cava that drains the lower extremities when the maternal position is supine. There is a significant reduction of venous return to the heart and consequently a reduction of cardiac output.

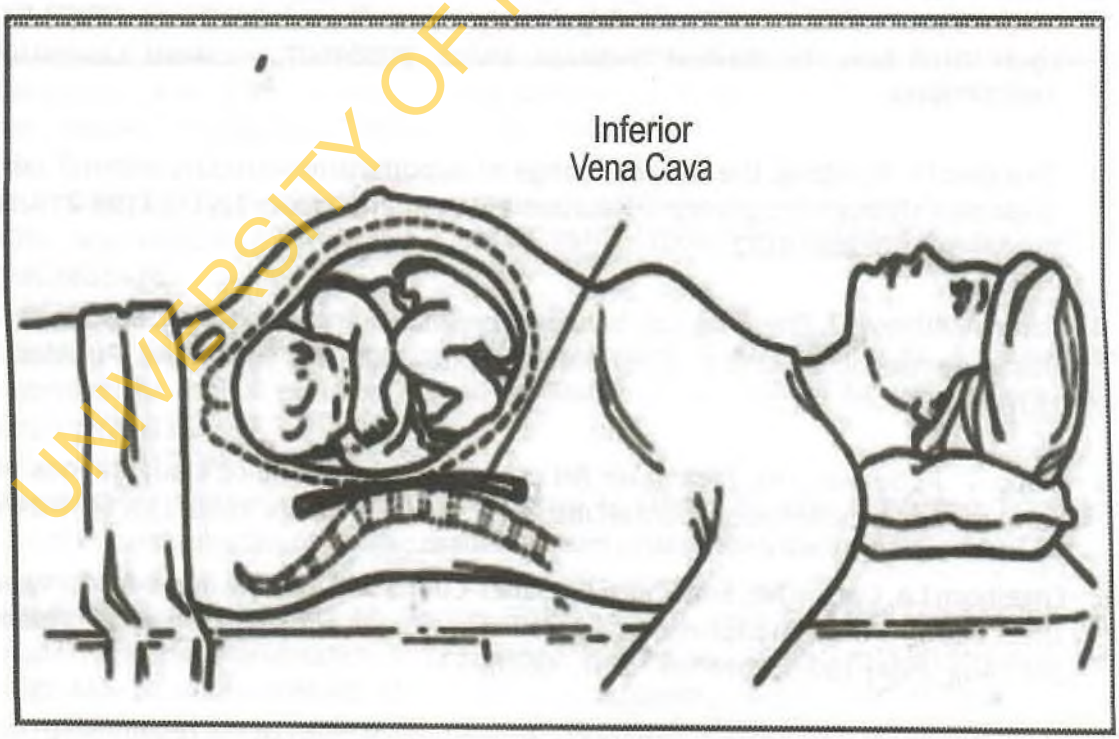

Figure 26.2: Pregnant woman lying supine is at risk of supine hypotension syndrome

EVALUATION OF CARDIOVASCULAR SYSTEM IN PREGNANCY

Pregnant women with CVS disorder often present with exaggerated symptoms and signs. It is important for clinicians to take every complaint seriously, examine and offer investigations to compliment the evaluation. The key clinical features that might suggest CVS disorders include: chest pain, dyspnoea on exertion, orthopnea, paroxysmal nocturnal dyspnoea, fatigue, palpitation, postural hypotension, pedal oedema (rapidly developing), dizziness and syncopy. It is advisable to engage the service of senior obstetrician and or cardiologist. Useful investigations that may be necessary to resolve these symptoms are: Electrocardiography, Echocardiocardiography, and Chest x-ray with lead shield may be necessary.

CLINICAL CORRELATES

CVS changes in pregnancy in most cases appear physiological but, these changes could compromise maternal physiology to warrant admission and sometimes in extreme cases result in termination of pregnancy. A good example is the patient with pre-existing heart disorders. Another clinical issue that could affect CVS status is postural positions that mothers adopt during procedures (obstetric scan, anaesthesia and long term examinations) after mid-pregnancy upwards. Left lateral position should be adopted for long term procedures to prevent reduction of venous return and blood supply to the fetus. Drugs that could affect CVS physiology in pregnancy include: Anti-hypertensive drugs, tocolytic agents- β sympathomimetic agents.

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