UNIT 3 DEVELOPMENT OF THE HEART

Structure

3.0 OBJECTIVES

After reading this unit, you should be able to:

- describe the formation of heart tube;
- know the genesis of atrium, ventricles and atrioventricular canal; and
- enlist the name of the major congenital heart disease and their formation.

3.1 INTRODUCTION

The primordium of the heart forms in the cardiogenic plate located at the cranial end of the embryo. Angiogenic cell clusters which lie in a horse-shoe shape configuration in the plate coalesce to form two endocardial tubes. These tubes are then forced into the thoracic region due to cephalic and lateral foldings where they fuse together forming a single endocardial tube.

The tube can be subdivided into primordial heart chambers starting caudally at the inflow end. They are as follows:

- the sinus venosus
- primitive atria
- ventricle
- bulbus cordis

The heart tube begins to grow rapidly forcing it to bend upon itself. The result is the bulboventricular loop. Septa begin to grow in the atria, ventricle and bulbus cordis to form right

and left atria, right and left ventricles and two great vessels-the pulmonary artery and the aorta. By the end of the eighth week partitioning is completed and the fetal heart has formed. Details discussion of the fetal heart formation will be under the following sections:

- Formation of the heart tube
- Partitioning of the atria
- Fate of the sinus venosus (Formation of the right atrium)
- Pulmonary veins (Formation of the left atrium)
- Atrioventricular canals
- Formation of the ventricles
- Partitioning of the outflow tract

Congenital Heart Disease

- Atrial septal defect
- Persistent atrioventricular canal
- Ventricular septal defect
- Transposition of great vessels
- Persistent truncus arteriosus
- Tetralogy of Fallot
- Dextrocardia

3.2 HEART TUBE FORMATION

The origins of the heart tube are clusters of angiogenic cells which are located in the ***cardiogenic plate***. The cardiogenic plate, which is derived from splanchnoplueric mesoderm, is located cranial and lateral to the neural plate.

These ***angiogenic cell clusters coalesce*** to form right and left ***endocardial tubes***. Each tube is continuous cranially with a dorsal aorta, its outflow tract, and caudally with a vitteloumbilical vein, its inflow tract.

The lateral and cranial folding of the embryo forces the tubes into the thoracic cavity. As a result, these tubes come to lie closer to each other and begin to fuse in a cranial to caudal direction.

The newly formed ***heart tube*** bulges into the pericardial cavity and is attached to the dorsal wall by a fold of tissue, the dorsal mesoderm. This is a derivative of foregut splanchnoplueric mesoderm. Eventually this will rupture leaving the heart tube suspended in the pericardial cavity anchored cranially by the dorsal aortae and caudally by the vitelloumbilical veins.

As it bulges into the cavity it becomes invested in a layer of myocardium. A layer of acellular matrix, the cardiac jelly, separates the myocardium and the endothelial heart tube.

The newly formed heart tube may be divided into ***regions***. Starting caudally Fig. 3.2 and 3.3).

- **sinus venosus** consisting of right and left horns paired
- **primitive atria** fuse together and form common atrium.
- **atrioventricular sulcus** divides the atria and the primitive ventricle.
- **primitive ventricle** expands to become the left ventricle.
- **interventricular sulcus** divides the primitive ventricle and the bulbus cordis.
- **bulbus cordis** which may be divided as follows:
  - bulbus cordis–the proximal portion forms the right ventricle
  - conus cordis
  - truncus arteriosus
- **aortic sac**

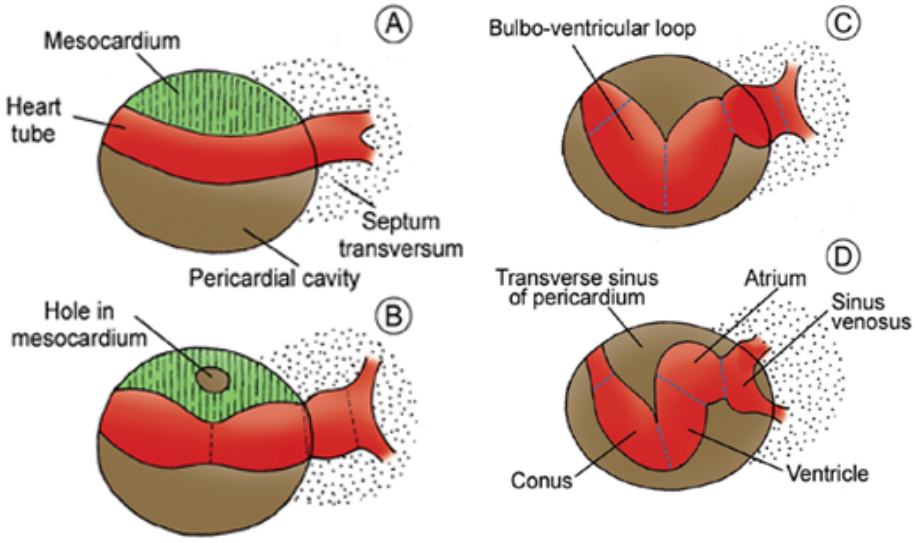

Fig. 3.1: Folding of heart tube

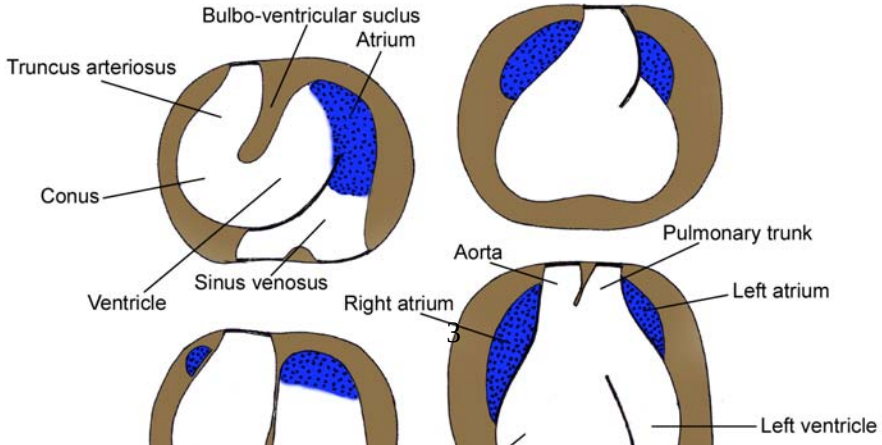

Fig. 3.2: Development of external form of the heart

Check Your Progress 1

Enlist the sub-division of heart tube and their fate.

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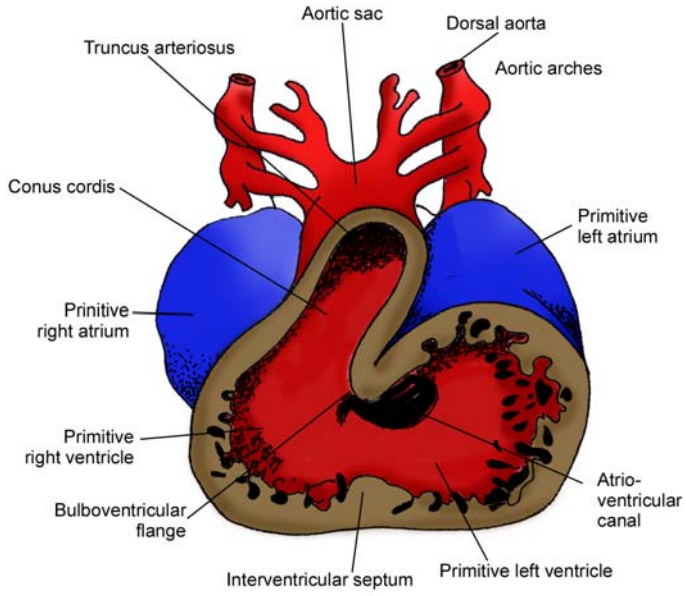

Fig. 3.3: Frontal section through the heart

3.3 ATRIAL PARTITIONING

By the time the heart tube has formed the bulboventricular loop, the two primitive right and left atria have fused to form a common atrium. Note that it now lies cranial to the primitive ventricle and dorsal to the bulbus cordis. The truncus arteriosus lies on the roof of the common atium causing a depression and indicates where septation of the atrium will occur.

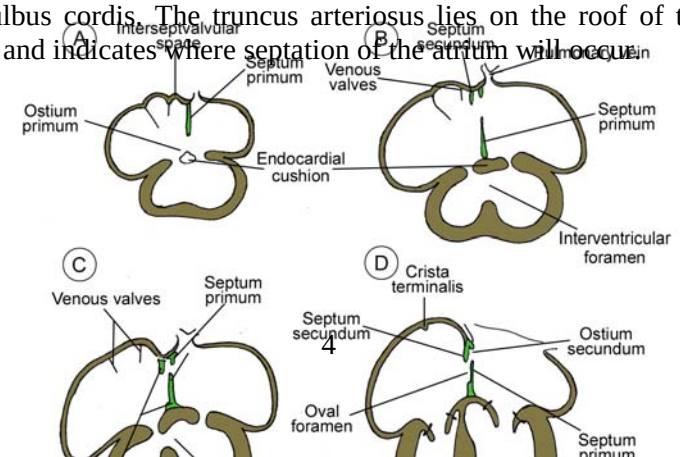

Fig. 3.4: Schematic representation of atrial septa at various stages of development

The partitioning of the atrium begins with the appearance of *septum primum* at about the 28th day. This is a crest of tissue that grows from the dorsal wall of the atrium towards the endocardial cushions—the ostium (opening) formed by the free edge of septum primum is the *ostium primum*.

Before the septum primum fuses with the endocardial cushions, perforations appear in the upper portion of the septum primum. These perforations will coelasce to form the ostium secundum.

Unlike the septum primum, septum secundum does not fuse with the endocardial cushions. Its free edge forms the foramen ovale. The left venous valve and the septum spurium, located on the dorsal wall of the right atrium, fuse with the septum secundum as it grows.

At the end of the seventh week the human heart has reached its final stage of development. Because the fetus does not use its lungs, most of the blood is diverted to the systemic circulation. This is accomplished by a right to left shunting of blood that occurs between the two atria.

The foramen ovale and the septum primum control this right and left communication. The septum primum acts as a valve over the foramen ovale. At birth the child will use its lungs for the first time and consequently more blood will flow into the pulmonary circulation. The pressure increase in the left atrium (where the pulmonary veins empty) will force septum primum to be pushed up against septum secundum. Shortly thereafter the two septa fuse to form a common atrial septum.

3.4 FATE OF THE SINUS VENOSUS (FORMATION OF THE RIGHT ATRIUM)

Unlike the atria, the sinus vinosus remains a paired structure with right and left horns. Each horn receives venous blood from three vessels:

- Vitelline vein
- Umbilical vein
- Commom cardinal vein

Communication between the sinus venosus and the primitive atrium, the sinoatrial oriface, is centrally located.

Gradually the sinoatrial oriface shifts to the right, due to the shunting of blood to the right, until the sinus venosus communicates with only the right atrium. The fate of each structure is as follows:

- the right sinus horn becomes enlarged.

- the right anterior cardinal vein becomes the superior vena cava.
- the right vitelline vein becomes the inferior vena cava.
- the right umbilical vein is obliterated.

Conversely, the left vein counterparts are obliterated and the left sinus horn diminishes in size and forms the *coronary sinus and the oblique vein of the left ventricle.*

Internally, the sinoatrial oriface is flanked by two valves, the right and left venous valves. Superiorly these two valves meet to form the *septum spurium.* Note that the left horn opens up underneath the oriface of the right horn (sinoatrial oriface). This is the *orifice of the coronary sinus.*

Further into development the right sinus horn is incorporated into the expanding right atrium. As the atrium expands the smooth tissue of the sinus venosus displaces the trabeculated tissue of the primitive right atrium anteriorly and laterally where it becomes the adult *right auricle.* The smooth tissue forms part of the atrium called the *sinus venarum. Crista Terminalis,* a ridge of tissue located to the right of the sinoatrial oriface, forms the boundry between the auricle and the sinus venarum.

Pulmonary Veins (Formation of the Left Atrium)

Development of the left atrium occurs concurrently with that of the right atrium. During the early part of the fourth week an outgrowth of the pulmonary veins appear from the left atrium (Fig. 3.5). This "sprout" will bifurcate until there are four veins. These vessels will then grow towards the lung buds.

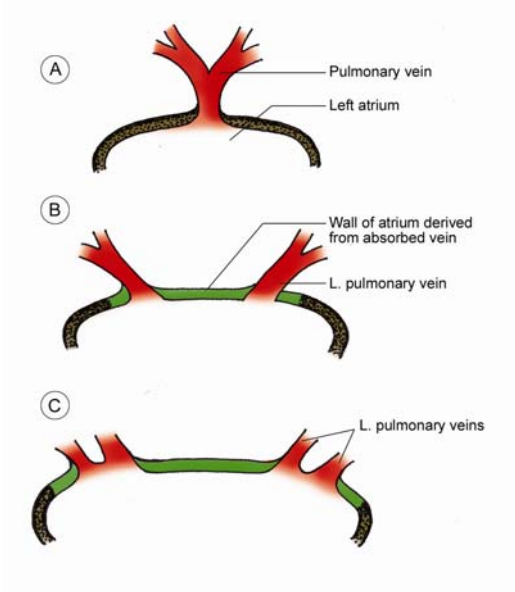

Fig. 3.5: Formation of the left atrium

The left atrium begins to expand gradually intussuscepting the four branches. As the atrial wall expands, the smooth tissue of the pulmonary veins is incorporated into the wall of the atrium and displaces the trabeculated tissue anteriorly and laterally which will then form the adult auricles. Compare this process to the formation of the adult right auricle.

Atrioventricular Canals

Recall that the proximal bulbus cordis gives rise to the right ventricle. Thus, blood flows from the primitive atrium to the left ventricle then to the right ventricle. There is no direct communication between the atria and the right ventricle even after the formation of the bulboventriclular loop. The atrioventricular canal must shift to the right in order to achieve communication to the right ventricle in addition to the left ventricle. During this shift the proximal bulbus widens and the bulboventricular flange begins to recede. Swellings of mesenchymal tissue, the endocardial cushions, appear on the borders of the atrioventricular canal. There are four cushions: inferior and superior (ventral and dorsal), left and right. The first appear before the latter. These swellings give the atrioventricular canal a "dog's bone" shape.

At approximately day 42 the superior and inferior cushions fuse forming a right and a left atrioventricular canal. The left atrium communicates with the left ventricle and the right atrium communicates with the right ventricle. The shifting process brings the conus cordis to lie superior to the interventricular foramen, which at this point, has not yet been obliterated. The fused endocardial cushions are also responsible for the closure of the ostium primum by fusing with the free edge of the septum primum.

Check Your Progress 2

1) Describe the formation on left atrium.

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2) Describe the formation of atrioventricular canals.

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3.5 FORMATION OF THE VENTRICLES

In the newly formed bulboventricular loop the primitive right and left ventricles appear as expansions in the heart tube. Externally the interventricular sulcus separates the right and left ventricles and internally they are separated by the bulboventricular flange. Remember that the right ventricle arises from the proximal bulbus cordis.

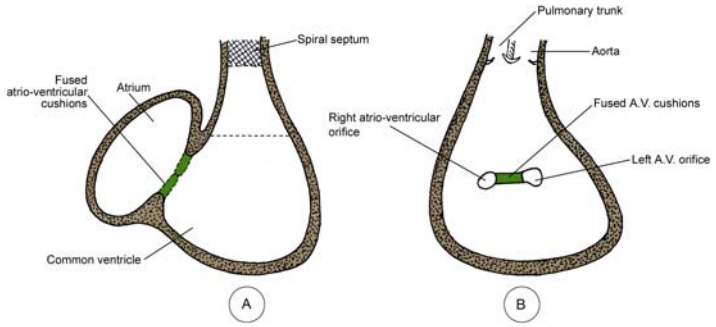

Fig. 3.6: Formation of two-parts of the ventricular chamber

During the shifting of the atrioventricular canal the proximal bulbus cordis expands forming the right ventricle. Both ventricles will continue to expand until the late 7th/early 8th week. The growth of the ventricles is due to the centrifugal growth of the myocardium and the diverticulation of the internal walls. (This is what gives the ventricle its trabeculated appearance). The muscular interventricular septum forms as a result of the expanding ventricles. The walls of

the right and left ventricules grow in opposition to each other to form the muscluar septum. Thus, the septum will cease to grow when the ventriclar walls are no longer expanding.

Partitioning of the Outflow Tract (Fig. 3.7)

The final morphological change in the heart is the partitioning of the outflow tract—the truncus arteriosus and the conus cordis—into the aorta and the pulmonary trunk. This is accomplished by the development of a septum that forms in the outflow tract and the emergence of the two great vessels.

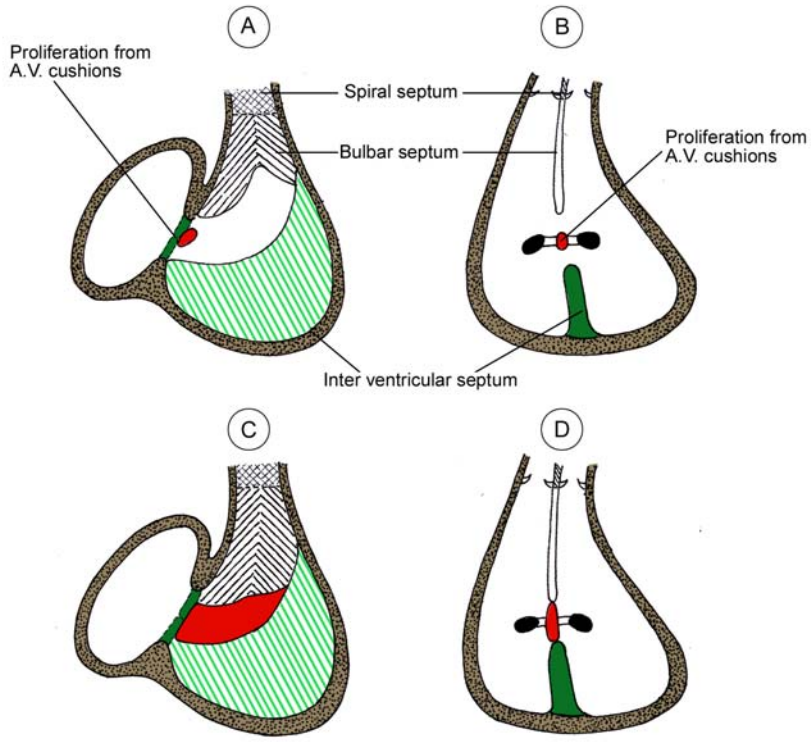

Fig. 3.7: Stages of Development of Ventricular Septum

The septum forms from two pairs of swellings which grow from the walls of the outflow tract. These are the *truncus swellings* and the *conus swellings.*

Truncal Swellings: *Right superior* which grows distally and to the left. *Left inferior* which grows distally and to the right. Both develop at the proximal part of the truncus and proceed to grow in two directions; 1) distally towards the aortic sac and 2) into the lumen of the outflow tract where they will eventually fuse together.

Conus Swellings: *Right dorsal* which is continuous with the right superior *Left ventral* which is continuous with the left inferior Like the truncal swellings, the conal swellings grow distally and towards each other, however they appear after the first pair. These conus swellings eventually fuse with the truncal swellings.

3.6 CONGENITAL HEART DISEASE

Atrial Septal Defect

In a heart with an Atrial Septal Defect (ASD) there is communication between the right and left atria which causes a left to right shunting of blood due to the lower pressure in the pulmonary circulatory system. Consequently there is a mixing of oxygenated (systemic) and deoxygenated (pulmonary) blood.

There are two types of ASD:

- ***Primum type*** involves the endocardial cushions.
- ***Secundum type*** involves septum primum or septum secundum.

Persistent Atrioventricular Canal

The persistent atrioventricular canal results from the failure of the superior and inferior cushions to fuse. Thus there is a single atrioventricular canal in which all four chambers may freely communicate. Because the cushions do not fuse the atrial and ventricular septa cannot fully form as they rely on the cushions to form the membranous portions of these septa.

Ventricular Septal Defect (VSD)

The ventricular septal defect is the most common of all congenital heart anomalies. It may be caused by any of the four malformations:

- Deficient development of the proximal conus swellings.
- Failure of the muscular portion of the interventricular septum to fuse with the free edge of the conus septum. (Membranous VSD)
- Failure of the endocardial cushions to fuse.
- Excessive diverticulation of the muscular septum-perforations in the muscular interventricular septum. (Muscular VSD)

In the case of a VSD there is a massive left to right shunting of blood and pulmonary hypertension is also observe. The absence of the interventricular septum results in a Common Ventricle.

Transposition of the Great Vessels

Transposition is a condition in which the aorta arises from the right ventricle and the pulmonary trunk from the left. This anomally is due to the failure of the truncoconal swellings to grow in the normal spiral direction. There is also a ventricular septal defect and a patent ductus arteriosus. However, these secondary defects make life possible as they provide a way for oxygenated blood to reach the entire body.

Persistant Truncus Arteriosus

A persistent truncus arteriosus results when the truncoconal swellings fail to grow. The single artery, the truncus arteriosus, arises from both ventricles above the ventricular septal defect, allowing pulmonary and systemic blood to mix. Distally, the single artery is divided into the aorta and pulmonary trunk by an incomplete septum.

Tetralogy of Fallot

This condition results from a single error i.e. the conus septum develops too far anteriorly giving rise to two unequally proportioned vessels — a large aorta and a smaller stenotic pulmonary trunk. The four main characteristics of Tetralogy of Fallot are:

- pulmonary stenosis
- ventricular septal defect (VSD) of the membranous portion (the septum is displaced too far anteriorly to contribute to the septum)
- overriding aorta (the aorta straddles the VSD)
- right ventricular hypertrophy due to the shunting of blood from left to right. (The pressure in the right ventricle is increased causing the walls of the right ventricle to expand.)

Dextrocardia

Dextrocardia is an anomaly in which the primitive heart tube folds to the left in a mirror image of a normal bulboventricular loop. This usually occurs when all the organ systems are reversed, a condition called *situs inversus.*

Check Your Progress 3

1) What are the types of atrial septal defect?

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2) What are the causes of formation of ventricular septal defect?

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3) What are the four characteristics of Tetralogy of Fallot?

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3.7 LET US SUM UP

In this unit, you have learnt that the clustering of angiogenic cells formed the heart tube which is vulges into pericardial cavity. Right atrium formed from sinus venosus and left atrium formed from pulmonary veins. The ventricles are derived from the primitive ventricular chamber and the proximal part of the bulbus cordis (conus). The pulmonary and aortic valves are derived from endocardial conshions.

You have also learnt that different type of congenital heart diseases i.e. atrial septal defect, ventricular septal defect, transposition of the great vessels and tetralogy of fallot and embryological causes of these diseases.

3.8 ANSWERS TO CHECK YOUR PROGRESS

Check Your Progress 1

The heart tube begins to grow rapidly forcing it to bend upon itself. The result is the bulboventricular loop. Septa begin to grow in the atria, ventricle and bulbus cordis to form right and left atria, right and left ventricles and two great vessels- the pulmonary artery and the aorta. By the end of the eighth week partitioning is completed and the fetal heart has formed.

Check Your Progress 2

1) Development of the left atrium occurs concurrently with that of the right atrium. During the early part of the fourth week an outgrowth of the pulmonary veins appear from the left atrium. This "sprout" will bifurcate until there are four veins. These vessels will then grow towards the lung buds.

   The left atrium begins to expand gradually intussuscepting the four branches. As the atrial wall expands, the smooth tissue of the pulmonary veins is incorporated into the wall of the atrium and displaces the trabeculated tissue anteriorly and laterally which will then form the adult auricles.

2) There is no direct communication between the atria and the right ventricle even after the formation of the bulboventriclular loop. The atrioventricular canal must shift to the right in order to achieve communication to the right ventricle in addition to the left ventricle. The endocardial cushions, appear on the borders of the atrioventricular canal. There are four cushions: inferior and superior (ventral and dorsal), left and right.

   The superior and inferior cushions fuse forming a right and a left atrioventricular canal. The left atrium communicates with the left ventricle and the right atrium communicates with the right ventricle.

Check Your Progress 3

1) •□□Secundum type involves septum primum or septum secundum.

   • Primum typeinvolves the endocardial cushions.

2) • Deficient development of the proximal conus swellings.

   • Failure of the muscular portion of the interventricular septum to fuse with the free edge of the conus septum. (Membranous VSD)

   • Failure of the endocardial cushions to fuse.

   • Excessive diverticulation of the muscular septum- perforations in the muscular interventricular septum. (Muscular VSD)

3) • pulmonary stenosis

   • ventricular septal defect (VSD) of the membranous portion

   • overriding aorta (the aorta straddles the VSD)

   • right ventricular hypertrophy due to the shunting of blood from left to right.

3.9 FURTHER READINGS

Singh Inderbir; *Human Embryology*; 5th edn; 1993, Mac Millan India Limited.

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