

Introduction

Pediatric cardiac disease is defined as an abnormality in cardiocirculatory structure or function that is present at birth, event if it is discovered much later (***Friedman and Silverman, 2001***).

The incidence of pediatric cardiac disease is approximately 6 to 8 per 1000 births.

The palliative surgeries as classic BlaLock-Taussig shunt and modified BlaLock-Taussig shunt for ToF and corrective surgeries as repair of VSD and ASD now being done commonly at a younger age and the survival of such patients have improved. The general anesthesiologist will therefore frequently encounter patients with pediatric cardiac problems presenting for non cardiac surgery (***Mohindra et al., 2002***).

The care of such patients is far from routine. The presence of pediatric cardiac disease increases the risk for non cardiac surgery (***Morroy et al., 2000***).

The aim of this study is to understand the existing anatomy and pathophysiology with an organized plan to effectively care for these children.

Each patient's anesthetic plan needs to be tailored according to the age, cardiac lesion, extent of palliative or corrective surgery if any, and the presence of cardiac complications or other congenital abnormalities (***Mohindra et al., 2002***).

Anatomical & Physiological Considerations in Pediatric Patients

Anatomy of the heart

The heart has four chambers—two atria and two ventricles. The internal partition that divides the heart longitudinally is called the interatrial septum where it separates the atria, and the interventricular septum where it separates the ventricles. The right ventricle forms most of the anterior surface of the heart. The left ventricle dominates the inferoposterior aspect of the heart and forms the heart apex. Two grooves visible on the heart surface indicate the boundaries of its four chambers and carry the blood vessels supplying the myocardium. The coronary sulcus, or atrioventricular groove, encircles the junction of the atria and ventricles like a crown (corona = crown). The anterior interventricular sulcus, cradling the anterior interventricular artery, marks the anterior position of the septum separating the right and left ventricles. It continues as the posterior interventricular sulcus, which provides a similar landmark on the heart posteroinferior surface (*Noecker et al., 2006*).

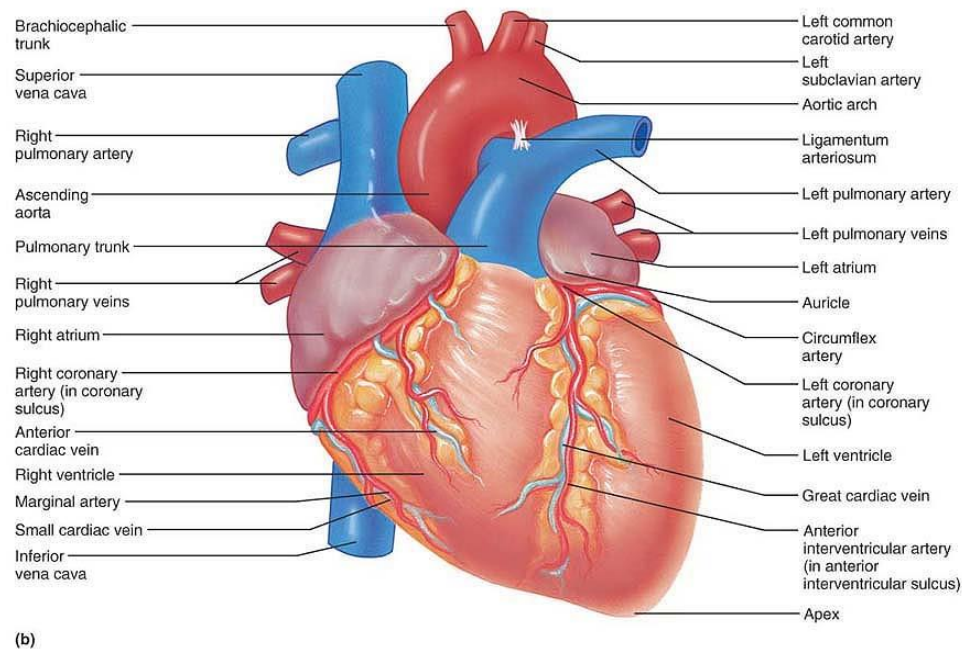


Figure (1): Anatomy of the heart. In diagrammatic views, vessels transporting oxygen-rich blood are red; those transporting oxygen-poor blood are blue. Anterior view (Noecker *et al.*, 2006).

Atria: The Receiving Chambers

Except for small, wrinkled, protruding appendages called auricles, which increase the atrial volume somewhat, the right and left atria are remarkably free of distinguishing surface features. Internally, the right atrium has two basic parts a smooth-walled posterior part and an anterior portion in which the walls are ridged by bundles of muscle tissue. Because these bundles look like the teeth of a comb, these muscle bundles are called pectinate muscles (pectin = comb). The posterior and anterior regions of the right atrium are separated by a C-shaped

ridge called the crista terminalis (“terminal crest”). In contrast, the left atrium is mostly smooth and undistinguished internally. The interatrial septum bears a shallow depression, the fossa ovalis, that marks the spot where an opening, the foramen ovale, existed in the fetal heart. Functionally, the atria are receiving chambers for blood returning to the heart from the circulation (atrium = entryway). Because they need to contract only minimally to push blood “downward” into the ventricles, the atria are relatively small, thin-walled chambers. As a rule, they contribute little to the propulsive pumping activity of the heart (*Seemann et al., 2006*).

Blood enters the right atrium via three veins: (1) The superior vena cava returns blood from body regions superior to the diaphragm; (2) the inferior vena cava returns blood from body areas below the diaphragm; and (3) the coronary sinus collects blood draining from the myocardium. Four pulmonary veins enter the left atrium, which makes up most of the heart’s base. These veins, which transport blood from the lungs back to the heart, are best seen in a posterior view (*Vincke et al., 2006*).

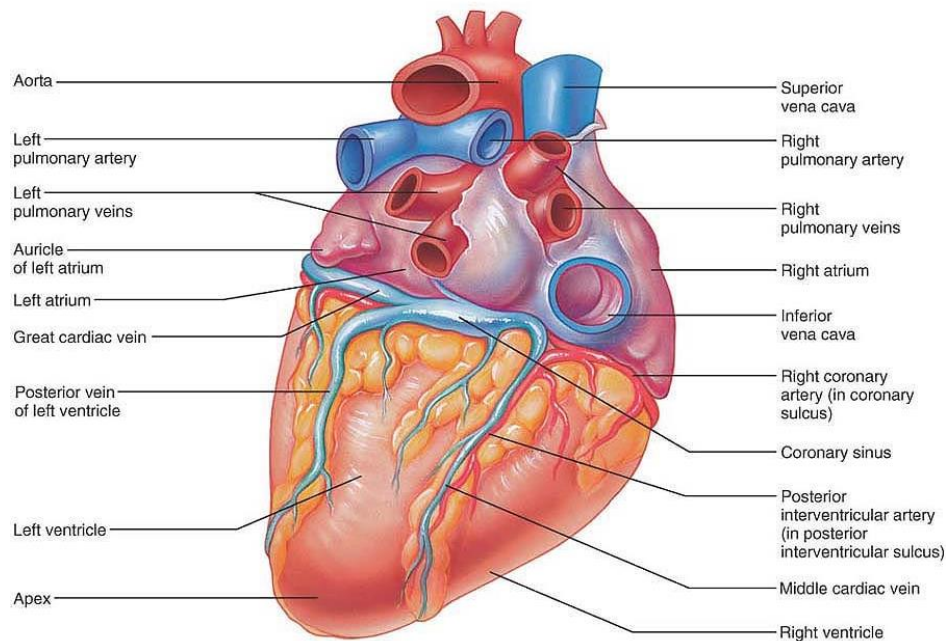


Figure (2): Anatomy of the heart,post surface view. In diagrammatic.view, vessels.transporting oxygen rich blood are red, those transporting oxygen poor blood are blue (Noecker et al.,2006).

Ventricles: The Discharging Chambers

Together the ventricles (ventr = underside) make up most of the volume of the heart. As already mentioned, the right ventricle forms most of the heart's anterior surface and the left ventricle dominates its posteroinferior surface. Marking the internal walls of the ventricular chambers are irregular ridges of muscle called trabeculae carneae (trah-bek'u-le kar'ne-e; "crossbars of flesh"). Still other muscle bundles, the conelike papillary muscles, which play a role in valve function, project into the ventricular cavity. The ventricles are the discharging chambers or actual pumps of the heart (the difference in

function between atria and ventricles is reflected in the much more massive ventricular walls). When the ventricles contract, blood is propelled out of the heart into the circulation. The right ventricle pumps blood into the pulmonary trunk, which routes the blood to the lungs where gas exchange occurs. The left ventricle ejects blood into the aorta, the largest artery in the body (*Moore, 1992*).

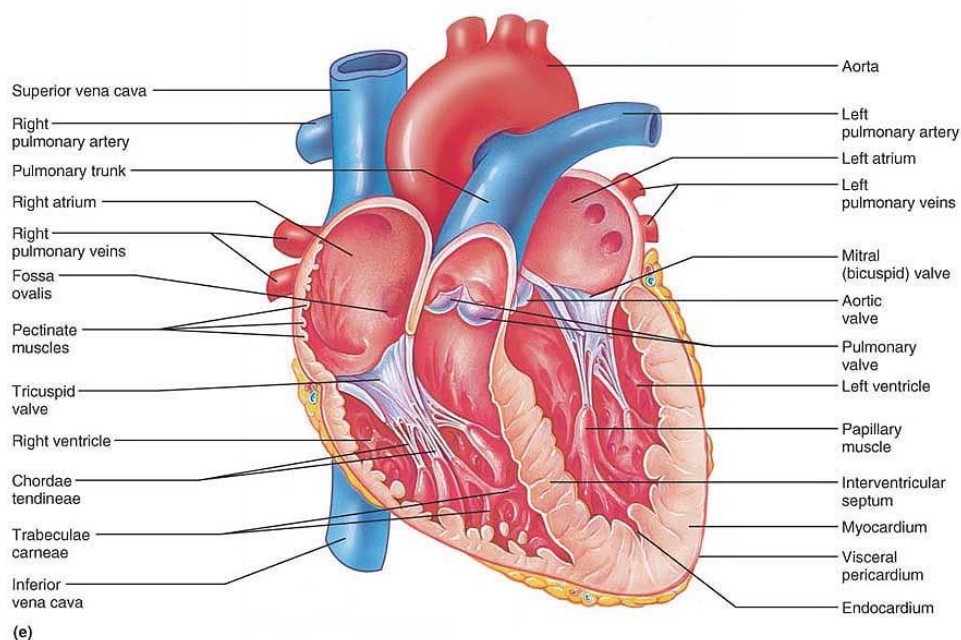


Figure (3): Anatomy of the heart. Frontal section showing interior chambers and valves (*Noecker et al., 2006*).

HEART VALVES

Blood flows through the heart in one direction: from atria to ventricles and out the great arteries leaving the superior aspect of the heart. This one-way traffic is enforced by four

valves that open and close in response to differences in blood pressure on their two sides (**Kirklin and Barratt, 1993**).

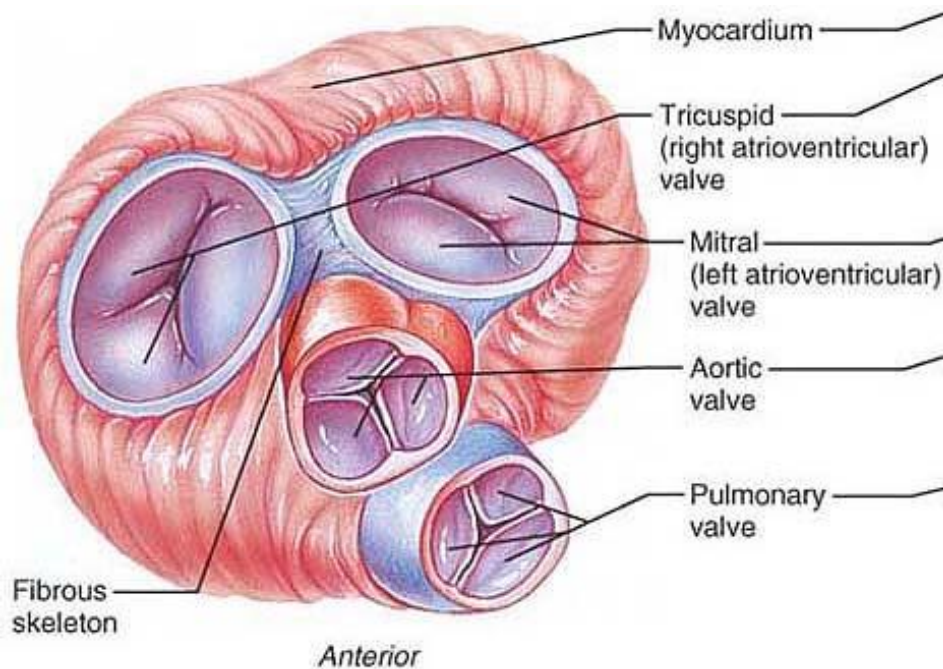


Figure (4): Anatomy of the heart cross section showing heart valves (**Seemann et al., 2006**)

Atrioventricular Valves

The two atrioventricular (AV) valves, one located at each atrial-ventricular junction, prevent backflow into the atria when the ventricles are contracting. The right AV valve, the tricuspid valve has three flexible cusps (flaps of endocardium reinforced by connective tissue cores). The left AV valve, with two flaps, is called the mitral valve (mitral) because of its resemblance to the two-sided bishop's miter or hat. It is sometimes called the

bicuspid valve. Attached to each AV valve flap are tiny white collagen cords called chordae tendineae “heart strings” which anchor the cusps to the papillary muscles protruding from the ventricular walls (**Moore, 1992**).

When the heart is completely relaxed, the AV valve flaps hang limply into the ventricular chambers below and blood flows into the atria and then through the open AV valves into the ventricles. When the ventricles contract, compressing the blood in their chambers, the intra-ventricular pressure rises, forcing the blood superiorly against the valve flaps. As a result, the flap edges meet, closing the valve. The chordae tendineae and the papillary muscles serve as guide to anchor the valve flaps in their closed position. If the cusps were not anchored in this manner, they would be blown upward into the atria, in the same way an umbrella is blown inside out by a gusty wind. The papillary muscles contract before the other ventricular musculature so that they take up the slack on the chordae tendineae before the full force of ventricular contraction hurls the blood against the AV valve flaps (**Seemann et al., 2006**).

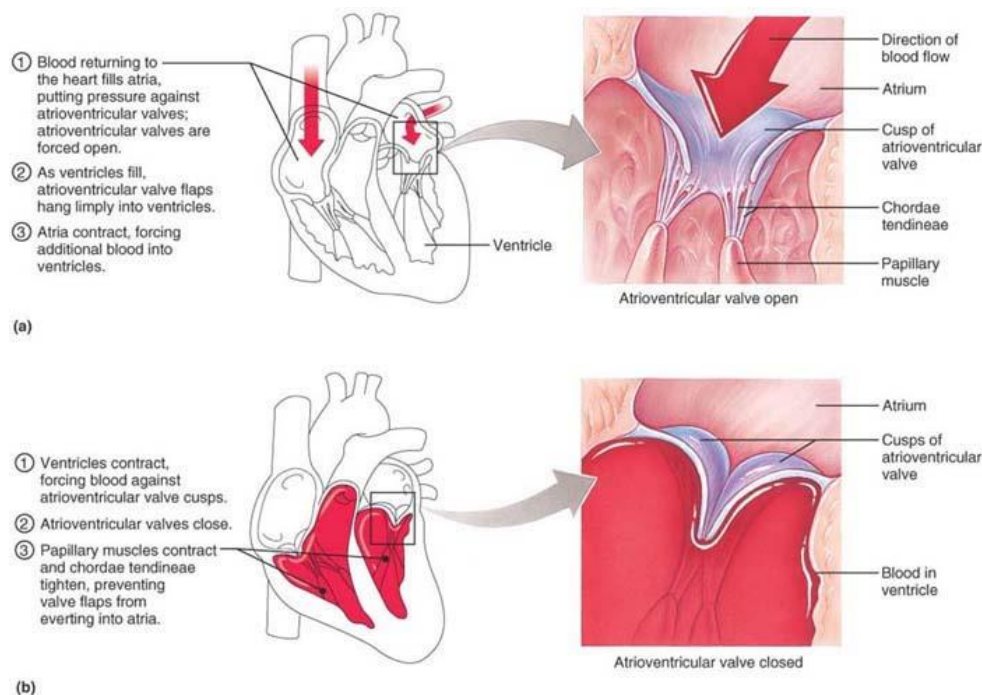


Figure (5): The atrioventricular valves. (a) The valves open when the blood pressure exerted on their atrial side is greater than that exerted on their ventricular side. (b) The valves are forced closed when the ventricles contract and intraventricular pressure rises, moving the contained blood superiorly. The action of the papillary muscles and chordae tendineae keeps the valve flaps closed (Seemann *et al.*, 2006).

Semilunar Valves

The aortic and pulmonary (semilunar, SL) valves guard the bases of the large arteries issuing from the ventricles (aorta and pulmonary trunk, respectively) and prevent backflow into the associated ventricles. Each SL valve is fashioned from three pocketlike cusps, each shaped roughly like a crescent moon (semilunar = half-moon). Like the AV valves, the SL valves open and close in response to differences in pressure. In the SL

case, when the ventricles are contracting and intraventricular pressure rises above the pressure in the aorta and pulmonary trunk, the SL valves are forced open and their cusps flatten against the arterial walls as the blood rushes past them. When the ventricles relax, and the blood (no longer propelled forward by the pressure of ventricular contraction) flows backward toward the heart, it fills the cusps and closes the valves (Noecker *et al.*, 2006).

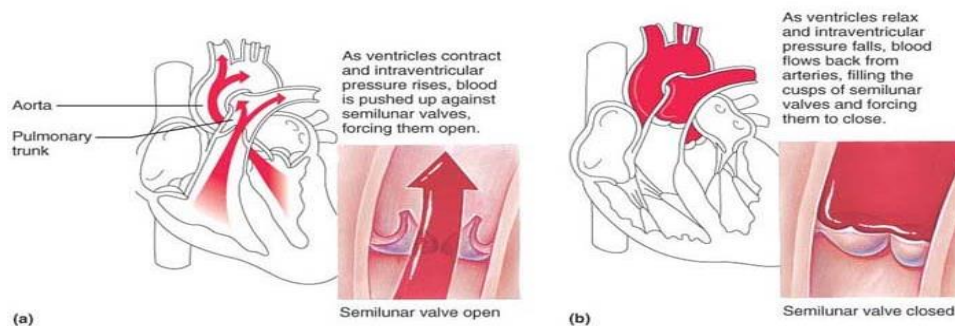


Figure (6): The semilunar valves. (a) During ventricular contraction, the valves are open. (b) When the ventricles relax, the backflowing blood closes the valves. Noecker *et al.*, 2006)

We complete the valve story by mentioning what seems to be an important omission—there are no valves guarding the entrances of the venae cavae and pulmonary veins into the right and left atria, respectively. Small amounts of blood do spurt back into these vessels during atrial contraction, but backflow is minimal because of the inertia of the blood and because as it contracts, the atrial myocardium compresses (and collapses) these venous entry (Vincke *et al.*, 2006).

Physiology of the Heart

Pathway of Blood Through the Heart

Until the sixteenth century, it was believed that blood moved from one side of the heart to the other by seeping through pores in the septum. We now know that the heart passages open not from one side to the other but vertically and that the heart is actually two side-by-side pumps, each serving a separate blood circuit. The blood vessels that carry blood to and from the lungs form the pulmonary circuit (pulmonos = lung), which serves gas exchange. The blood vessels that carry the functional blood supply to and from all body tissues constitute the systemic circuit (*Costanzo, 1995*).

The systemic and pulmonary circuits. The right side of the heart pumps blood through the pulmonary circuit (to the lungs and back to the left side of the heart). The left side of the heart pumps blood via the systemic circuit to all body tissues and back to the right side of the heart. Blood flowing through the pulmonary circuit gains oxygen and loses carbon dioxide, indicated by the color change from blue to red. Blood flowing through the systemic circuit loses oxygen and picks up carbon dioxide (red to blue color change) (**Fig. 7**) (*Gomella and Haist, 2003*).

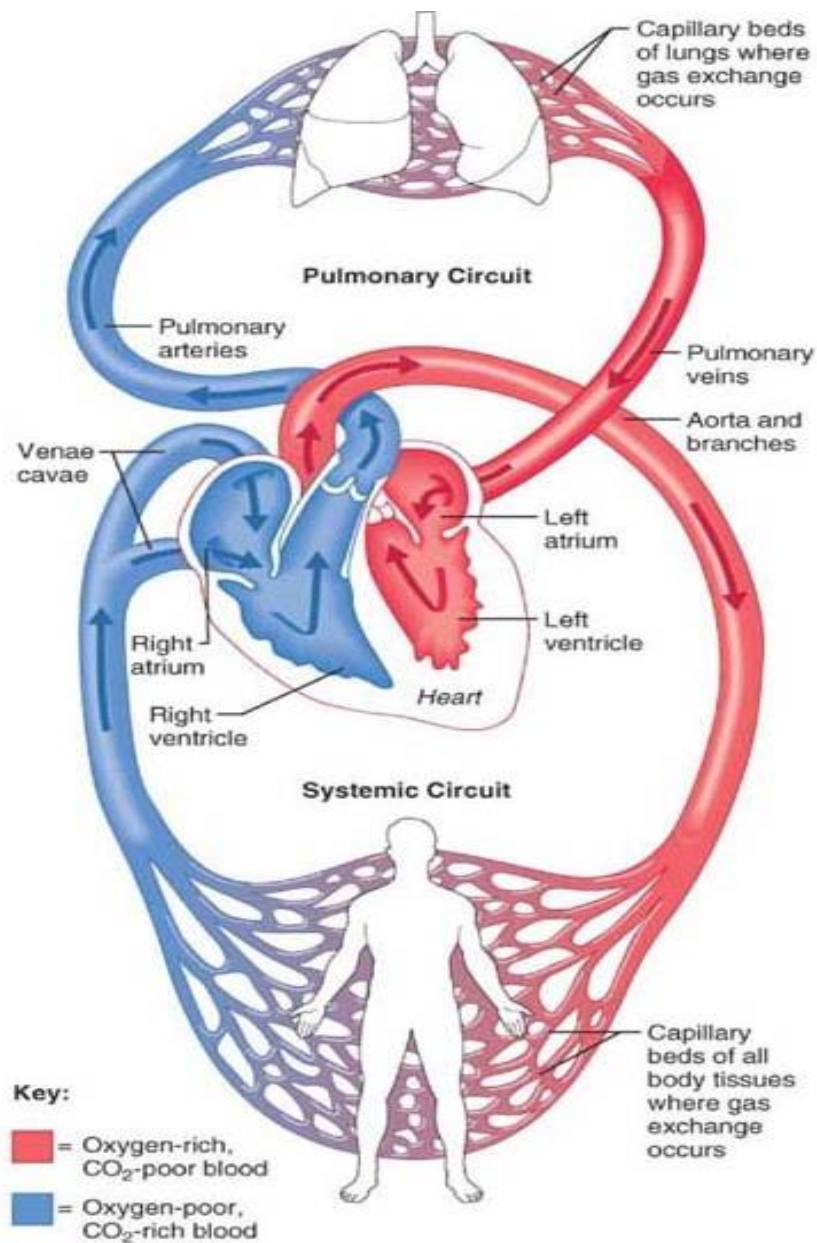


Figure (7): Show pulmonary and systemic circulation
(Gomella and Haist, 2003)

The right side of the heart is the pulmonary circuit pump. Blood returning from the body is relatively oxygen-poor and carbon dioxide-rich. It enters the right atrium and passes into the right ventricle, which pumps it to the lungs via the pulmonary trunk. In the lungs, the blood unloads carbon dioxide and picks up oxygen. The freshly oxygenated blood is carried by the pulmonary veins back to the left side of the heart. Notice how unique this circulation is. Typically, we think of veins as vessels that carry blood that is relatively oxygen-poor to the heart and arteries as transporters of oxygen-rich blood from the heart to the rest of the body. Exactly the opposite condition exists in the pulmonary circuit (**Costanzo, 1992**).

The left side of the heart is the systemic circuit pump. Freshly oxygenated blood leaving the lungs is returned to the left atrium and passes into the left ventricle, which pumps it into the aorta. From there the blood is transported via smaller systemic arteries to the body tissues, where gases and nutrients are exchanged across the capillary walls. Then the blood, once again loaded with carbon dioxide and depleted of oxygen, returns through the systemic veins to the right side of the heart, where it enters the right atrium through the superior and inferior venae cavae. This cycle repeats itself continuously (**Behraman et al., 1992**).

Although equal volumes of blood are pumped to the pulmonary and systemic circuits at any moment, the two ventricles have very unequal workloads. The pulmonary circuit,

served by the right ventricle, is a short, low-pressure circulation, whereas the systemic circuit, associated with the left ventricle, takes a long pathway through the entire body and encounters about five times as much friction, or resistance to blood flow. This functional difference is revealed in the anatomy of the two ventricles. The walls of the left ventricle are three times as thick as those of the right ventricle, and its cavity is nearly circular. The right ventricular cavity is flattened into a crescent shape that partially encloses the left ventricle, much the way a hand might loosely grasp a clenched fist. Consequently, the left ventricle can generate much more pressure than the right and is a far more powerful pump (*Costanzo, 1995*).

Foetal and Neonatal Circulation

A- Foetal circulation:

Oxygenated blood from the placenta flows to the foetus through the umbilical vein. Approximately 50% of the umbilical venous blood bypass the liver and flows through the ductus venosus into the inferior vena cava, where it mixes with the remainder of the venous return from the caudal part of the body and enters the right atrium from the inferior vena cava. Most of this blood preferentially passes across the foramen ovale to the left atrium, flows into the left ventricle, and is ejected into the ascending aorta. The superior vena caval blood,

which is considerably less oxygenated, traverse the tricuspid valve and flows primarily to the right ventricle and pulmonary arterial trunk. The major portion of this blood bypasses the lungs and flows through the ductus arteriosus into the descending aorta to perfuse the caudal part of the body as well as the placenta via the umbilical arteries (*Behrman et al., 1992*).

Approximately 10% of the right ventricular output flows to the lung via the pulmonary arteries, and 90% enters the descending aorta via the ductus arteriosus. This occurs primarily because pulmonary vascular resistance in the foetus is considerably higher than systemic resistance, which is predominantly influenced by the low-resistance placental vascular bed.

B- Neonatal circulation:

At birth, the foetal circulation must immediately adapt to extrauterine life as gas exchange is transferred from the placenta to the lung. After an initial fall in systemic blood pressure, there is a progressive rise. The heart slows as a result of a baroreceptor response to an increase in systemic vascular resistance when the placental circulation is eliminated. With the onset of ventilation, a marked increase in pulmonary blood flow occurs because of the dilatative effect of oxygen on the pulmonary arteriolar bed. Pulmonary venous return and consequently left ventricular output are thus increased. In the