This instructional guide was prepared for use with the DON JAKE SAUNDERS HEART MODEL from Medical Plastics Laboratory, Inc., of Gatesville, Texas.

The purpose of this guide is to provide a comprehensive introduction to the anatomy of the human heart for students of allied health professions as well as college and university students. One of the objectives is to provide an introduction to the gross structure of the human heart using the DON JAKE SAUNDERS HEART MODEL to illustrate the structural relationships. The other objective is to apply the knowledge of the anatomy of the heart to heart function. This guide is not intended to be a detailed or lengthy discussion of cardiac physiology.

The numbers in parentheses in the text of this guide refer to the key code numbers on the model. Two types of key code lists have been included. The first lists all coded structures in numerical order while the second has the numbers grouped according to location on the model.

The index lists all structures in alphabetical order. The bold faced numbers in the index refer to key code numbers and the regular type numbers refer to page numbers.

Recognition and thanks goes to Dr. Robert Daley of Ohio University, who has read the manuscript and has given the benefit of his constructive criticism.

For the illustrations, I am indebted to Mr. Danny Smith of Medical Plastics Laboratory, Inc. for his excellent work.

Last but certainly not least, special recognition must be given to the late DON JAKE SAUNDERS (1921-1976) of Medical Plastics Laboratory, Inc., who sculpted the heart model which bears his name. His expertise as a medical artist has lead to the development of a model which is second to none in accuracy and detail.

Grover C. Ericson
Grover C. Ericson, Ph.D.
INTRODUCTION

The heart is a muscular organ that acts as a double pump; the right side receives deoxygenated blood from the body and pumps it to the lungs while the left side receives the oxygenated blood from the lungs and pumps it to the rest of the body. The aorta acts as the receiving chambers of the heart and the ventricles as the pumping chambers.

The heart begins to beat toward the end of the first month of embryonic development and must continue to beat for the duration of the individual's life. In a lifetime of 70 years, the heart would beat over 2.5 billion times and would pump over 41 million gallons (158 million liters) of blood. If the heart were to stop for even a short time, irreversible changes would occur and death would quickly follow.

This remarkable muscular pump is about the size of the individual's clenched fist. The DON JAKE SAUNDERS HEART MODEL is approximately three times this size.

LOCATION

The heart is located in the central portion of the thorax called the mediastinum, which divides the thorax into left and right cavities (pleural cavities) that contain the lungs. It lies in the lower portion of the mediastinum behind and a little to the left of the sternum, and above the middle portion of the diaphragm. The upper portion of the mediastinum contains the large blood vessels (great vessels) entering and leaving the heart.

PERICARDIUM

A double-walled sac known as the pericardium encloses the heart and the roots of the great vessels (Figure 6). The outer fibrous layer (fibrous pericardium) is attached below to the diaphragm. Above it blends with the outer layers of the great vessels. The fibrous pericardium serves to limit the movement of the heart. The inner layer of the pericardium (serous pericardium) is a closed sac. It lines the fibrous pericardium (and is known as the parietal serous pericardium) and is reflected around the roots of the great vessels and becomes continuous with a layer (visceral serous pericardium) on the surface of the heart. Between the two layers is the pericardial cavity. A small quantity of serous pericardial fluid, secreted by the cells of the serous layers, fills the limited space of the cavity. This fluid permits frictionless movement of the heart when it beats. The DON JAKE SAUNDERS HEART MODEL presents the anatomy of the heart with the fibrous and parietal serous pericardium removed.

![Fig. 1. Section through the thoracic cavity showing the organization of the serous and fibrous parts of the pericardium. The pericardial cavity lies between the parietal and visceral layers of the serous pericardium.](Z35)
EXTERNAL ANATOMY

When the model is sitting on its wooden base, it is in the correct anatomical position. In this position, the right border of the heart is formed by the right atrium (96). The left border is formed by the left ventricle (2) and a small part of the auricle of the left atrium (4).
The sternocostal (or anterior) surface of the heart is composed of the auricle of the right atrium (3) and the right and left ventricles (1.2). The right auricle (3) and right ventricle (4) are separated from one another by the conus arteriosus (or conus arteriosus) sulcus or groove which contains, in addition to fat, the right coronary artery (23). The coronary sulci continues around the heart (95,96) and the ventricles (1.2). The right and left ventricles on the anterior surface are separated by the anterior interventricular sulcus which contains the anterior interventricular (or anterior descending) artery (30) and great cardiac vein (51).

The heart is cone-shaped and the posterior surface of the heart is the base of the cone. The base (or posterior surface) of the heart is formed mainly by the left atrium (95) into which the pulmonary veins (50,51) open, the right atrium (96) also forms a small portion of the surface.

The apex of the heart lies opposite the base and is formed by the left ventricle (2). It points downward, forward, and to the left. In the anatomical position, the heart, the apex taps the chest wall at the level of the fifth intercostal space (15 cm) from the midline (a little below and medial to the left nipple of the male). The apex beat can usually be seen or palpated in the left axillary line except when the apex strikes the rib rather than the muscle of the space.

HEART WALLS

The walls of the heart consist of three layers: the inner "endocardium," the middle "myocardium" and the outer "epicardium."
The epicardium is a thin smooth glistening membrane which lines all of the chambers of the heart and is continuous with the inner lining of the blood vessels entering the heart. The endocardium also forms the valves of the heart which will be discussed in greater detail below.

The myocardium is the thickest layer of the heart wall and consists of muscle cells, called myocytes, which are responsible for the heart's ability to contract and pump. A fibrous septal musculature of the atria from the ventricles and surrounds the openings of the blood vessels entering and leaving the heart. The epicardium also forms the valves of the heart which will be discussed in greater detail below.

CIRCULATION THROUGH THE HEART

The direction of blood flow through the heart is indicated by blue and red arrows on the model. The heart receives blood by way of the veins and pumps it out through the arteries. Deoxygenated blood (blue arrows) from the upper part of the body, drains into the superior vena cava (8) and then into the right atrium (96). Blood from the lower part of the body enters the right atrium (96) through the inferior vena cava (60). From the right atrium (96), the blood passes through the tricuspid valve (93) into the right ventricle (1). When the ventricles contract, the blood is pumped through the pulmonic valve (64) into the pulmonary trunk (6) and then to the lungs by way of the pulmonary arteries (12,49). The pulmonary trunk (6) and arteries (12,49) transport deoxygenated blood and are, therefore, color coded in blue in the model. Oxygated blood (red arrows) from the lungs returns to the left atrium (95) through the coronary veins of the heart (50,51). After passing through the pulmonic (mitral) valve (94) into the left ventricle (2), the oxygenated blood is pumped through the aortic valve (60) to be distributed throughout the body by the aorta (8) and its branches (Figure 2).

BLOOD SUPPLY OF THE HEART

Coronary Arteries

An abundant supply of oxygenated blood reaches the myocardium by way of an extensive capillary network which surrounds each muscle fiber. This capillary network is supplied by branches of the right and left coronary arteries (23,28).

At the origin of the aorta (5) just above the aortic valve (80), there are three fairly distinct projections in the aortic wall called aortic sinuses, one opposite each of the three cusps of the valve (104-105). The coronary arteries arise from the aortic sinuses opposite the left and right cusps (105,104). On the DON JUNE SAUNDERS HEART MODEL, the left coronary artery is the red dot immediately above the left cusp (105) which is on the right coronary artery, which is shown on the diagram as the anterior left coronary artery (104) as the anterior left coronary artery (104). The right coronary artery is shown on the diagram as the anterior left coronary artery (104).

The right coronary artery (23) passes between the root of the pulmonary trunk (4) and the aorta, the left and right atrium (3) and then runs downward and to the right in the coronary sulci. After forming the right margin of the heart to run to the left in the posterior

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**Color Code**
- Arteries: Red
- Veins: Blue
- Lymphatics: Green
- Nerves: Off-White

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**Fig. 2.** Scheme of the systemic and pulmonary circulation. Oxygenated blood is shown in dot pattern; deoxygenated blood in line shading. The arrows indicate the direction of blood flow.
part of the sulcus together with the small cardiac vein (33) and anomatomes with the circumflex branch of the left coronary artery (29). Three major branches of the right coronary artery (23) are shown on the model. The first branch, one of the anterior right atrial branches (24), originates near the origin of the right coronary artery (23) under cover of part of the right auricle (3). One of the branches off of the right coronary artery (24) is of great importance. This branch is the superior vena cava branch (nodal ar-
tery) (25) which supplies the sinoatrial node (86). The second major branch of the coronary artery is the right marginal artery (28) which descends along the right border of the heart and supplies the myocardium of the right ventricle (1). As the right coronary artery passes the posterior interventricular sulcus, it gives off the posterior interventricular (or posterior descending) artery (27) which supplies the adjacent portions of the myocardium of both ven-
tricles as well as part of the interventricular septum (97).

The left coronary artery (38) arises from behind the left aortic cusp (103) and passes between the pulmo-
atory trunk (6) and the auricle of the left auricle (4) to reach the coronary (atrioventricular) sulcus. Upon reaching the sulcus, the left coronary artery (28) branches into the anterior interventricular (or ante-
rior descending) artery (30) and the circumflex artery (29). The anterior interventricular artery (30) de-
scends in the anterior interventricular sulcus and in many subjects turns around the apex of the heart and runs a variable course in the posterior inter-
ventricular sulcus. This artery and its branches (30A) supply the myocardium of both ventricles and part of the interventricular septum (79) and also anomatomes with the posterior interventricular artery (27). The circumflex branch (29) is the continuation of the left coronary artery (28) in the coronary sulcus. It anomatomes with the right coronary artery (23) in the sulcus on the posterior aspect of the heart. Branches off of the circumflex artery supply the upper portion of the left ventricle (2) and the adjacent left auricle. Left marginal branches of the circumflex (not num-
bered on the model) extend along the left border of the heart.

The anomatomes between the branches of the coronary arteries are at the level of the arterioles. These small branches of the coronary arteries are functionally end-artries, since the anomatomes through them are not adequate to maintain suf-
icient collateral circulation if a large branch of a coronary artery were to suddenly become ob-
structed. If, on the other hand, the obstruction devel-
oped gradually, the small vessels of the anomatomes could enlarge to provide some measure of relief to the affected area.

Coronary Veins

The capillary bed of the myocardium is supplied with blood from the coronary arteries and is drained by the coronary veins. These veins follow the arteries in the coronary (atrioventricular) and interventricular su-
culi and are usually superficial to the arteries. Most of the veins drain into a widened venous channel, the coronary sinus (34), located in the posterior por-
tion of the coronary sulcus. The coronary sinus (34) drains into the right atrium (96) between the opening of the inferior vena cava and the tricuspid valve (see number 82 inside the right auricle).

The main tributaries of the coronary sinus are:
1. The great cardiac vein (36) which begins near the apex and ascends in the anterior interventricular sulcus to reach the coronary (atrioventricular) sulcus. It follows this sulcus to the left and around to the back of the heart where it enters the beginning of the coronary sinus (34). In its course, the great cardiac vein accompanies the anterior interventricular ar-
tery (30) and the circumflex branch of the left coro-
nary artery (29).
2. The middle cardiac vein (37) begins near the apex and ascends in the posterior interventricular sulcus and drains into the coronary sinus (34) near its ter-
mination. The middle cardiac vein parallels the pos-
terior interventricular artery (27).
3. The small cardiac vein (33) usually begins as the right marginal vein. After reaching the coronary sulcus it turns to the right following the sulcus to the back of the heart where it enters the coronary sinus (34) near its termination. The small cardiac vein (33) accompanies at first the right marginal artery (28) and then the right coronary artery (23) after it reaches the coronary (atrioventricular) sulcus.
4. The posterior vein of the left ventricle (36) ascends along the diaphragmatic surface and left margin of the heart and drains into the left end of the coronary sinus (34) near its beginning.
5. The oblique vein of the left aurium (36) descends obliquely over the left atrium and drains into the left end of the coronary sinus (34).

The anterior cardiac veins (32) are small vessels which ascend on the anterior wall of the right ven-
tricle (1), cross the coronary sulcus above the right coronary artery (23) and open directly into the right atrium. The venous cords minima (smallest cardiac or Thebesian veins) are minute veins in the myo-
cardium which open directly into the heart cham-
bers. These veins are too small to be shown on the model.

INTERNAL FEATURES OF THE HEART

With the four doors of the DON JAKE SAUNDERS HEART MODEL open, note the thickness of the mus-
cular walls of each chamber— the aorta have considerably thinner walls than the ventricles. This difference reflects the fact that the atria act as re-
eiving chambers of the heart and the ventricles as the pumping chambers. Each of the four chambers has its own charac-
teristic appearance, structure and related vessels.

Right Atrium

The thin walled right atrium receives deoxy-
genated blood from the body by way of the vena
cava (8,60) and from the heart itself by way of the coronary sinus (34) and anterior cardiac veins (32). The vena cavae are in line with one another; the superior vena cava (8) enters the right atrium ver-
tically from above while the inferior vena cava (60) enters it vertically from below. The coronary sinus

DON JAKE SAUNDERS HEART MODEL

Regional Key Code

Internal

98. Membranous Septum (Interventricular Part)
99. Atrioventricular Bundle (of His)
101. Anterior Cusp - Pulmonic Valve
102. Right Cusp - Pulmonic Valve
103. Left Cusp - Pulmonic Valve
108. Purkinje Fibers

Internal Left Aurium

50. Left Pulmonary Veins
51. Right Pulmonary Veins
87. Pulmonic Valve
92. Valve of Foramen Oval
94. Bicuspid (Mitral) Valve
95. Left Aurium

Internal Left Ventricle

64. Trabeculae Carneae
75. Anterior Papillary Muscle
77. Posterior Papillary Muscle
78. Anterior Cusp - Aortic Valve
79. Posterior Cusp - Bicuspid Valve
80. Aortic Valve
86. Membranous Septum (Interventricular Part)
104. Right (Coronary) Cusp - Aortic Valve
105. Left (Coronary) Cusp - Aortic Valve
106. Posterior (Non-Coronary) Cusp - Aortic Valve
107. Left Bundle Branch
108. Purkinje Fibers

Color Code

Arteries ................ Red
Veins ................. Blue
Lymphatics .............. Green
Nerves ................ Off-white
drains into the right atrium just to the left of the opening of the inferior vena cava (see 83 in the right atrium). The orifice of the superior vena cava has no valve. The orifice of the inferior vena cava has a rudimentary valve, the valve of the inferior vena cava (or Eustachian valve) (82), formed by a crescentic fold on the anterior margin of the orifice. This valve is more prominent in the fetus than in the adult due to the thick interventricular septum (97) bulging into its cavity.

Functionally the right ventricle can be divided into inflow and outflow portions. The inflow portion consists of the right atrioventricular (or tricuspid) valve (93), and the trabeculated (64) apical walls of the right atrium. The outflow portion, the conus arteriosus or infundibulum (65), has relatively smooth walls and leads upward to the pulmonic valve (66). The two divisions of the right ventricle are partially separated from one another by muscular ridges: the pectinate band (74), the supraventricular crest (64), and the septal band (62).

Blood flows from the right atrium into the right ventricle, which functions as the atrioventricular orifice. This orifice is encircled by a fibrous ring which makes up part of the atrioventricular septum that completely separates the myocardium of the atria from that of the ventricles. The orifice is guarded by the tricuspid (right atrioventricular) valve (93) so named because of the three somewhat triangular leaflets or cusps (72,73,74) which make up the valve. The cusps are named according to their positions: anterior (72), septal or medial (73), and posterior (74). The bases of the valves are attached to the fibrous ring around the orifice while the apex of each valve extends into the ventricle. The tendinous cords, the chordae tendineae (75), extend from the undersurface (ventricular side) of the cusps to cone-shaped muscular projections from the ventricular wall called papillary muscles. The anterior papillary muscle (69) is the largest and receives chordae tendineae from the anterior (72) and posterior (74) cusps. The posterior papillary muscle (68) receives chordae tendineae from the posterior (74) and septal (73) cusps. The septal (or medial) papillary muscle (70), located approximately where the supraventricular crest (65) meets the septal band (62) receives chordae tendineae from the anterior (72) and septal (73) cusps. Some chordae tendineae from the septal cusp attach directly to the septal wall. Papillary muscles are often represented by two or more parts.

In addition to the papillary muscles, the anterior and inferior walls of the inflow portion of the right ventricle are lined with irregular muscular ridges and bulges called trabeculae carneae (64). A muscular band, the septomarginal trabecula or moderator band (63) extends from the interventricular septum to the anterior wall where it joins the base of the anterior papillary muscle (69). It was named "moderator band" because at one time it was thought to prevent overdistention of the ventricle when filling with blood. The moderator band (63) contains part of the right bundle branch (67) of the atrioventricular bundle (of His) (59). The atrioventricular bundle (of His) (59) divides into right (87) and left (107) bundle branches in the inter..
ventricular septum (97) toward the posterior margin of the membranous part of the septum (98). From this point, the right bundle branch (67) courses towards the ventricular apex beneath the endocardium. Divi-
sions of the right bundle reach the anterior ventricu-
lar wall and the base of the anterior papillary muscle (69) through the septomarginal trabecula (modera-
tor band) (63). The divisions break up into a plexus of Purkinje fibers (108) which pass beneath the endo-
cardium to the greater part of the right ventricle where they end by becoming continuous with the myocardial fibers.

The funnel-shaped outflow portion of the right ven-
tricle, known as the conus arteriosus or infundibulum (65) is in the superior part of the ventricle. It has smooth walls and is continuous with the pulmonary trunk (6). The pulmonic valve (66) separates the in-
fundibulum from the pulmonary trunk. This valve con-
sists of three semilunar cusps (101,102,103) attached to the base of the wall of the pulmonary trunk. The pocket-like cusps are designated anterior (101), right (102) and left (103).

Left Atrium

Oxygenated blood from the lungs enters the left atrium (93) of the heart through four pulmonary veins (59,51). The orifices of these veins are not guarded by valves. The inner walls of the left atrium are smooth except in the auricle (4) where parallel ridges called pectinate muscles (67) are present. A semilunar depression on the septal wall of the left ventricle marks the location of the fossa ovalis (89) of the right atrium. Inferior to this depression is a crescentic ridge, the valve of the foramen ovale (92), which is a remnant of the septum that closed the foramen ovale at the time of birth.

Left Ventricle

The walls of the left ventricle are approximately two to three times the thickness of the right ventricle. The left ventricular cavity is somewhat conical in shape with the apex of the cone representing the apex of the heart. Most of the ventricular wall is covered with a fine network of irregular muscular ridges and bridges called trabeculae carneae (64) which are especially dense at the apex. The upper anterior part of the ventricle leading to the aortic valve (60) is relatively smooth. Two large papillary muscles arise from the anterior (76) and posterior (77) walls and are named accordingly. Chordae tendi-
neae (75) extend from the tips of the papillary mus-
cles to the ventricular surface (underside) of the cusps of the left atrioventricular valve (78,79). The valve is similar in composition to that of the tricuspid valve (93), except that it has only two cusps (bicuspid). The bicuspid valve (94) is commonly referred to as the mitral valve because of the resemblance of its two cusps to a bishop's mitre. The ante-
or cusp (78) is located between the aortic and left atrioventricular orifices, the posterior cusp (79) is lo-
cated behind and to the left of the orifice. The papil-

locary muscles (76,77) are located below the commis-
sures of the valve and chordae tendineae (75) ex-
tend from each muscle to the two cusps.

The left bundle branch (67) of the atrioventricular bundle (59) descends immediately beneath the en-
docardium as a broad band which divides into a small anterior and large posterior division. The two divisions divide into lesser divisions which in turn break up into a plexus of Purkinje fibers (108) in the trabeculae carneae (64) and papillary muscles (76,77).

The aortic orifice is guarded by the aortic sim-
lunar valve (80) composed of three pocket-like cusps: a right cusp (104), a left cusp (105) and a posterior cusp (106). The structure and mode of attachment of these cusps are similar to those of the pulmonic valve (66) except that they are larger, thicker and stronger. On the aortic side of the valve, behind each cusp, there is a pouch-like dilatation known as an aortic sinus. The left coronary artery (28) arises from behind the left cusp and the right coronary artery (23) from behind the right cusp. The left and right cusps are of-
ten referred to as “coronary” cusps. The posterior cusp (106) which is not associated with the origin of a coronary artery is referred to as the “noncoronary” cusp.

Interventricular Septum

The left and right ventricles are separated from one another by the interventricular septum. The sep-
tum bulges into the cavity of the right ventricle. On the surface of the heart, the anterior and posterior in-
traventricular grooves or sulci correspond to the margins of the septum. Most of the septum is thick and muscular (muscular interventricular septum) (97), but its upper part, is thin and fibrous (membranous septum) (98,99). On the left side, the membranous septum (98) lies below the junction of the right (104) and posterior (106) cusps of the aortic valve. On the right side, the membranous septum is crossed by the attached border of the septal cusp (73) of the tricus-
pid valve, which divides it into anterior and posterior parts. The anterior part separates the two ventricles from each other (membranous interventricular sep-
tum) (96). The posterior part separates the right atria from the left ventricle just below the aortic valve (membranous atrioventricular septum) (99).

During embryonic development, the membranous portion of the septum grows downward from the fibrous skeleton of the heart which separates the atria from the ventricles. Failure of the membranous septum to fuse with the muscular septum would result in an interventricular septal defect or a patent inter-
ventricular septum. Such a condition would result in leakage of oxygenated blood from the high pres-
sured left ventricle into the right ventricle.

HEART VALVES

The fibrous septum which separates the musculature of the atria from that of the ventricles is referred to as the fibrous skeleton of the heart and corresponds roughly to the plane of the atrio-
ventricular groove on the surface of the heart. When visualized with the atria removed, the fibrous skele-
ton appears as four fused rings of connective tissue, one for each heart valve. These rings form bases to which the heart valves are attached. The cusps of each valve consist of a reflection of the endo-
cardium strengthened by intervening layers of fibrous tissue.
The diaphragm and the body cavity. It is described in detail in Chapter 21. The diaphragm provides the main source of inspiratory muscle activity and is responsible for the movement of the thoracic cavity during respiration.

Lymphatic System

The lymphatic system provides for drainage of tissue fluid back into the venous system and also provides the main immune mechanism for the body. It is beyond the scope of this book to present a detailed discussion of the lymphatic system, however, the thoracic cavity contains major lymph channels and numerous lymph nodes, a brief discussion is appropriate.

Cells of the body get their nutritional material from tissue fluid that resembles plasma in chemical composition. This material passes through the blood capillaries into the tissue fluid. Waste products from the cells pass into the tissue fluid and most readily re-enter the capillaries. The lymph nodes therefore act as a filter for the lymphatic system to absorb these molecules and return them to the blood vascular system. Only a small part of the lymphatic system is demonstrated on the DON JAYKES SAUNDERS HEART MODEL and it is shown in green.

The tissue fluid is called lymph once it has entered the lymphatic system. This system begins in a network of lymph capillaries which collect the tissue fluids. The capillaries come together to form larger vessels, which drain into the regional lymph nodes. Lymphatic vessels carry the lymph from the lymph nodes eventually the lymph vessels join together forming lymphatic trunks which in turn join to form lymphatic ducts. The ducts empty into the subclavian vein at the junction of the internal jugular vein and subclavian vein.

The thoracic duct (44) drains the chest wall and the body below the diaphragm. This duct originates in the abdomen in a dilated structure called the cisterna chyli. In the thorax it is posterior to the esophagus (45) until it reaches the upper part of the thorax where it curves to the left. In the base of the heart it turns laterally to the left behind the common carotid artery (46) and internal jugular vein (47). It enters the venous system in the angle between the left internal jugular vein (17) and the left subclavian vein (16).

Lymphatic vessels from the upper left side of the body usually join the thoracic duct (44) just before it joins the venous system. The lymphatic vessels from the upper right side drain into the right lymphatic ducts, which joins the venous system in the comparable location on the right side of the body.

Lymph nodes in the thoracic cavity and the base of the neck are very abundant. Only a small number of nodes are shown on the DON JAYKES SAUNDERS HEART MODEL.

Tracheobronchial lymph nodes are located in the region of the tracheal bifurcation. The interior tracheobronchial nodes (56) are located in the angle below the bifurcation. The interior tracheobronchial nodes which are not numbered on the model, are in the angle between the trachea (46) and the superior mediastinal vein (16), which is also shown in green.

The DON JAYKES SAUNDERS HEART MODEL presents the position of the heart valves during ventricular relaxation (diastole) when the ventricles are being filled. At this time the atrioventricular valves (93, 94) are open and the pulmonic (66) and aortic (60) valves are closed.

Atrioventricular Valves

The right atrioventricular valve (93) consists of three leaflets and is, therefore, referred to as the "tricuspid" valve. The left valve (94) consisting of two cusps is known as the "bicuspid" valve or the "mitral" valve because of its resemblance to a bat wing.

The cusps are continuous at the annulus with the fibrous skeleton around each orifice. Since the commissures between the cusps vary in depth, and therefore the size of the mitral valve orifice, the cusps are usually incompletely separated from each other. The chordae tendineae (75) extend from the undersurface (ventricular side) close to the free ends of the cusps to papillary muscles.

The tricuspid valve (93) consists of anterior, septal (or medial) and posterior cusps. The anterior cusp (72), usually the largest, is attached to the anterior portion of the right atrioventricular orifice. The septal cusp (73) is attached medially along the interven- tricular septum. The posterior cusp (14) which is usually the smallest, is attached along the posterior-interior border of the orifice.

The three cusps of the tricuspid valve do not have independent motion. The large anterior papillary muscle (69) sends chordae tendineae (75) to both the anterior (72) and posterior (14) cusps. The posterior papillary muscle (68) sends its chordae tendineae to the septal (73) and the posterior (74) cusps. Chordae tendineae from the left papillary muscle (70) go to the anterior (72) and septal (73) cusps.

Some chordae tendineae to the septal cusp (73) arise directly from the septal wall. The bicuspid or mitral valve (94) consists of ante- rior (72), and posterior (70) cusps which are larger, thicker and stronger than those of the tricuspid valve.

The anterior cusp (70) is located anterior and to the right between the aortic and left atrioventricular orifices. The posterior cusp (71) is located posterior and to the left of the left atrioventricular orifice. There are usually two papillary muscles in the left ventricle, on the anterior (74) located on the anterior wall and a posterior (77) on the posterior interior wall. These papillary muscles occasionally show doubling as demonstrated by the papillary muscle (76) in the DON JAYKES SAUNDERS HEART MODEL. Chordae tendineae (75) go to both cusps from each papillary muscle.

Blood passing through the atrioventricular orifices into the ventricles, pushes the cusps aside. When the ventricles contract, the back pressure of the blood forces the cusps together to close the orifice. The papillary muscles contract with the ventricles and chordae tendineae are tightened thus holding the cusps in position and preventing their being averted into the atria. Dysfunction of a papillary muscle or rupture of a chordae tendineae may affect the support of the valve cusps and produce regurgitation of blood into the atrium. Closure of the atrioven- tricular valves causes the first heart sound; the "lub" of "lub-dub."

Aortic and Pulmonic Valves

The pulmonic (66) and aortic (60) valves are referred to as "semilunar" valves because each valve has three semilunar pocket-like cusps formed by reflections of the endocardial lining of the heart (Figure 3). The cusps are of approximately equal size. Their convex outer borders are attached to and sus-
HEART SOUNDS

During the cardiac cycle, sounds which may be heard with a stethoscope or by placing the ear close to the thoracic wall (Figure 6) are:

1. The “lub” is called the first heart sound and the “dub” the second sound. The first sound is caused by the closure of the aortic and mitral valves. The second sound is due to the rapid closing of the valves prevents backflow from the atria to the ventricles. Impulses transmitted through the chest to be heard as the first heart sound, the “lub” sound. Immediately after the first sound, the blood has pumped their contents into the aorta and pulmonary trunk, ventricular relaxation permits blood to flow backwards from the arterioles into the ventricles. This backflow causes the aortic and mitral valves to close suddenly creating the second heart sound, the “dub” sound. It is a pattern of “lub/dub/pause”/“lub/dub”/pause is audible. The interval between “lub” and “dub” represents systole (period of ventricular contraction) and the interval or pause between “dub” and “lub” represents diastole (period of ventricular relaxation).

A third normal heart sound is present in almost all individuals, however, in many, it is so faint to be detected without special equipment. This sound occurs during the rapid filling of the ventricles during diastole.

Cardiac murmurs are heart sounds during the cardiac cycle that are in addition to the normal sounds. They are caused by turbulence in the blood as it flows through the valves. Turbulence may be due to rapid blood flow through narrowed and elongated orifices or the formation and injection of venous diseases prevents adequate closure of the valves and the blood regurgitates back through the orifice. A cardiac murmur can be caused by anything that changes the blood flow through the heart and the heart valves.

An experienced clinician can readily differentiate between the sounds of the two AV valves or between the pulmonary and aortic valves by moving the head of the stethoscope about until the murmur is heard at maximum intensity. The location will indicate the effective valve.

Murmurs, which are the result of valves not closing adequately, are heard when the AV valves are involved and during diastole in the case of the pulmonary valves, or when the valves are involved and during systole in the case of the pulmonic or aortic valves. Murmurs caused by a narrowing of the orifice of the valve is in the case of the mitral or aortic valves are called systolic murmurs. Murmurs that are heard during systole and during systole in the case of the pulmonic or aortic valves.

A murmur during the interval between “dub” and “dub” is called a systolic murmur. A murmur heard during diastole, by moving the stethoscope to the left is called a diastolic murmur. The blood flow during the diastolic murmur could be located. Involvement of one of the AV valves would indicate possible stenosis. If the pulmonary or aortic valves are involved, it is possible that applying blood to regurgitate into the orifice during diastole.

THE AORTA AND ITS BRANCHES

The aorta (8) is the largest artery in the body and supplies oxygenated blood to the systemic arterial system. The aortic arch can be divided into three parts: the ascending aorta, the aortic arch, and the descending aorta.

The ascending aorta begins as a continuation of the left ventricle where it is covered by the pulmonic trunk (9). It is the diameter of the ascending aorta is about 3 cm. There are three branches from this part of the aorta: the brachiocephalic artery (9), the left common carotid artery (10), and the left subclavian artery (11).

The brachiocephalic (innominate) artery (9) is the largest branch of the aortic arch. Arising from the right side of the arch, it divides into the right common carotid (16) and the right subclavian (11) arteries.

The left common carotid artery (10) is the next branch and arises from the highest part of the arch. It runs almost straight upward along the side of the trachea. The left subclavian artery (11) is the second branch off the arch, runs superiorly and to the left to enter the base of the neck.

The external carotid, the internal carotid, and subclavian arteries arise differently, they have the same distribution on the two sides of the body. The communication between the left and right carotid systems is by the transverse aortic arch (12) and the left subclavian artery (11) along the trachea. At a level more superior than the innominate artery, the common carotid arteries give off the branches which are the major vascular supply to the head and neck.

The subclavian arteries course upward and laterally along the sides of the neck. They then run laterally and downward over the first rib. At the anterior border of the first rib, the subclavian arteries become the axillary arteries and the major vascular supply to the upper arm. The origins of the branches of the axillary arteries are shown on the DON JAY SAUNDERS HEART MODEL.

The vertebral arteries (15) are the transverse foramina of the upper six cervical vertebra and enters the foramen magnum. In its course it gives branches to the vertebral body, the spinal cord and the brain. The internal thoracic artery (18) arises from the inferior part of the sub-

CONDUCTION SYSTEM OF THE HEART

The heart is characterized by an automatic rhythmic beat. It is also under the influence of the autonomic nervous system (sympathetic and parasympathetic) which works by nervous impulses and the central nervous system to control the force and frequency of the beat according to the physiological needs of the individual. Even after the heart has been removed from the body and the heart rate slows, as a result of the central nervous system involvement, it will continue to beat since the heart is a muscle and the nervous system has only a regulatory influence.

The coordinated contraction of the atria and ventricles which results in the effective pumping of blood requires a system which distributes nervous impulses to the proper place and of the proper time. The conduction system is performed by the specialized group of cardiac muscle fibers which conduct impulses from the atria to the ventricles. This system is composed of the sinoatrial (SA) node (86), the atrioventricular (AV) node (86, 91), Bachmann’s bundle (87), the internodal tracts (88, 90), the atrioventricular bundle (89, 100), the atrioventricular bundle of His (90), the bundle branches (87, 107), and the Purkinje fibers (108).

Sinoatrial Node

The sinoatrial (SA) node (86) is located in the wall of the right atrium at the upper end of the crista terminalis (86) near the opening of the superior vena cava (86). The SA node is a sheet of atrial muscle and there are numerous nerve endings from the autonomic nervous system. The electrical impulses generated in the heart to contract rhythmically originate from the SA node which is, therefore, referred to as the "pacemaker" of the heart. The impulses spread in all directions from the SA node to the atrial myocardium. The impulse is also conducted from the SA node to a second mass of specialized cells, the atrioventricular (AV) node (90) by internodal tracts and atrioventricular nodal tract (90) and Bachmann’s bundle (87) are responsible for the spread of the impulse to the anterior and posterior internodal tracts. The spread of the impulse through the myocardium of the atrial walls takes about 0.1 second and both atria contract simultaneously. The impulse is not transmitted across the atrioventricular septum which separates the atria from the ventricles.

Atrioventricular Node

The atrioventricular (AV) node is located in the lower half of the coronary sulcus in the posterior attachment of the septal cusps (73) of the tricuspid valve. The structure of the AV node is such that there is a single AV node in that it is composed of a meshwork of modified cardiac muscle fibers. The fibers converge on the anterior and inferior margin of the node and form the atrioventricular (AV) bundle (of His) (90) which passes through the posterior septal wall and then continues conducting connective tissue of the atrioventricular septum. The AV bundle is the only conducting or muscular link between the atria and ventricles.

Impulses from the SA node are transmitted by the internodal tracts to the AV node in approximately 0.04 second. The propagation of the impulse through the AV node is delayed by 0.11 second before emerging in the AV bundle. This delay in transmission of the AV node permits the atria to contract and empty into the ventricles before the ventricles start to contract.

Atrioventricular Bundle and Branches

After passing through the fibrous atrioventricular septum, the AV bundle descends in the interventricular septum along the posterior margin of the membranous portion of the ventricular septum. A thin non-muscular septum (97) the AV bundle divides into right (67) and left (107) bundle branches.

The right bundle branch (67) is a slender group of fibers which carries the impulse across the interventricular septum towards the apex on the right side of the ventricular septum. Divisions of the right bundle branch break off into a pulp of Purkinje fibers (108) (named in honor of an anatomist) to the right atrium. This pathway is through the connective tissue to the greater part of the right ventricle where they exit by becoming continuous with the muscular fibers of the bundle branches.

The bundle branch (107) is a sheet of fibers which divides into major anterior and posterior divisions. The divisions diverge, on an equal plane, and fan out in all directions and form a plexus of Purkinje fibers (108) in the trabeculae carneae (muscle fibers). Small septal branches to myocardial muscle that have no septomarginal trabecula (moderator band) in the left ventricle. The Purkinje fibers are the only conducting bundle of myocardial fibers.

When reaching the AV node, the impulse is delayed about 0.11 second before being transmitted rapidly through the AV bundle and the Purkinje fibers.


THE AORTA IS KNOWN AS ANTERIOR (104), RIGHT (102) AND LEFT (103). THE CUSPS OF THE AORTIC VALVE ARE DESIGNATED RIGHT (104), LEFT (105) AND POSTERIOR (106). THE LOWERING OF THE CUSPS ARISE FROM THE AORTIC SINUSES BEHIND THE LEFT AND RIGHT AORTIC AND PULMONARY CUSPS, WHICH ARE SOMETIMES REFERRED TO AS "CORONARY" CUSPS. THE LEFT CORONARY CUSP, WHICH IS NOT ASSOCIATED WITH A CORONARY ARTERY, IS THE "NON-CORONARY."
ELECTROCARDIOGRAPHY

The electrical impulse which passes through the conduction system of the heart, leads to other tissues surrounding the heart and very weak currents are transmitted to the surface of the body. By placing electrodes (small metal plates) on the skin on any two sides of the heart, the impulse generated during each beat can be picked up, amplified and recorded by an instrument called an electrocardiograph. The recorded impulse can be displayed on a pen recorder or a cathode ray oscilloscope. The record so produced is called an electrocardiogram and abbreviated ECG (or EKG).

The ECG is a graph of voltage variations plotted against time. Figure 6 illustrates a typical normal ECG recorded with the electrodes on the left and right wrists (lead I). The vertical lines indicate time in seconds and horizontal lines, amplitude in millivolts. The R wave is caused by the impulse passing through the atria. The QRS complex corresponds to the impulse passing through the ventricles. The "I wave" is caused by the reestablishment of the original electrical properties of the ventricular muscle cells.

SYSTOLE AND DIASTOLE

The period during the cardiac cycle when the ventricles are contracting is termed "systole," and the period of ventricular relaxation is termed "diastole." The periods of systole and diastole can be noted from the electrocardiogram or from the heart sounds. Systole begins with the QRS complex and ends with the T wave or R begins with the first heart sound and ends with the second. Diastole begins with the end of the T wave and lasts until the onset of the QRS wave, or it begins with the second heart sound and ends with the first.

Cardiac Cycle

Diastole Systole Diastole (Rapid Filling)

Heart Sounds

During the intrathoracic life, the lungs do not function to aerate the blood; this process is carried out by the placenta. The fetus receives blood carrying oxygen and nutrients from the placenta by way of the umbilical vein (Figure 4). Blood flowing in the umbilical vein enters the liver and is largely shunted by the ductus venosus to the inferior vena cava where it mixes with deoxygenated blood returning from the caudal portions of the fetus. Most of the blood in the inferior vena cava, upon entering the right atrium, is directed through an atrial septum, the foramen ovale, into the left atrium thereby bypassing the lungs. In the left atrium, the blood mixes with some deoxygenated blood from the pulmonary veins and then enters the left ventricle to be pumped out into the systemic circulation. Most of which is oxygenated, supplies the coronary arteries, the head, neck and upper limbs. Such a vascular arrangement provides the heart and brain with blood of higher oxygen content than is supplied to other regions which are less sensitive to lower levels of oxygen.

Deoxygenated blood returning to the right atrium from the superior vena cava, mixes with a small amount of oxygenated blood from the superior vena cava and is directed through the tricuspid valve into the right ventricle to be pumped into the pulmonary trunk. Only a small quantity of blood in the pulmonary trunk returns to the left atrium. Most of the blood in the pulmonary trunk is shunted through a large vessel, the ductus arteriosus, connecting the left pulmonary artery directly to the aortic arch. Here it mixes with oxygenated blood from the left ventricle and is distributed to the lower portion of the body. Blood returns to the placenta to receive oxygen and nutrients through the umbilical arteries which are branches of the internal iliac arteries.

CIRCULATORY CHANGES AT BIRTH

At birth or soon afterwards there are a number of changes which occur in the circulatory organization (Figure 5). After respiration begins, the umbilical cord is ligated and the placental circulation is cut off. The umbilical vessels cease in their function and gradually become fibrous structures; the intra-abdominal part of the umbilical arteries become the internal umbilical ligaments, and umbilical vein becomes the ligamentum teres hepatis or round ligament of the liver. The ductus venosus between the umbilical vein and the inferior vena cava closes and forms the ligamentum venosum of the liver.

When respiration begins, the lungs expand, decreasing their resistance to blood flow and thus increasing the amount of blood flowing through them. At this time, the ductus arteriosus closes rapidly, thus diverting all the pulmonary arterial blood to the pulmonary trunk through the lungs. The ductus arteriosus obliterations, become the ligamentum arteriosum (13). The pressure in the left atrium becomes equal to that in the right and the flap valve of the foramen ovale (12) closes and fuses to the interatrial wall. The foramen ovale (15) of the adult heart indicates the former location of the foramen ovale.

Failure of the foramen ovale or the ductus arteriosus to close allows deoxygenated blood to mix with oxygenated and results in a "blue baby." The severity of the condition depends on the size of the opening; when it is large, it is incompatible with life. Modern surgical techniques can be employed to correct these conditions.

Fig. 6. The cardiac cycle correlated with ECG and heart sounds.
Fig. 4. Circulation of blood in the fetus. The arrows indicate the direction of blood flow. Note the flow through the heart and compare with the flow after birth shown in Figure 5.

Fig. 5. Circulation of blood after birth. Areas where changes occurred at time of, or shortly after, birth are indicated.