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Study Guide

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Doc. #1004800

Don Jake Saunders

Heart Model

Study Guide

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PREFACE

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.

CONTENTS

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 atria act 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 2½ 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 life 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 1). 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 (viseral serous pericardium) on the surface of the heart. Between the two serous 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.

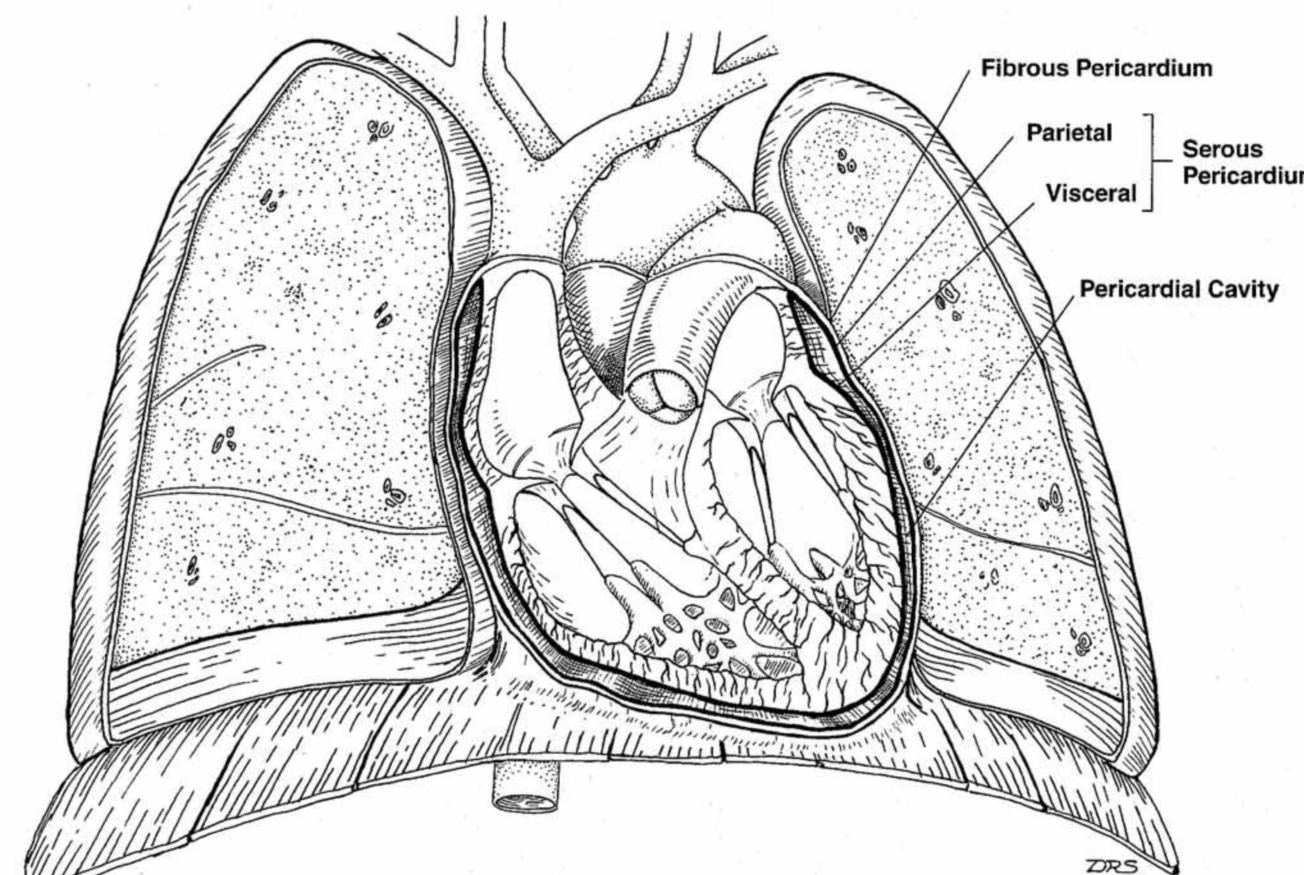


Fig. 1. Section through the thoracic cavity showing the organization of the serous and fibrous parts of the pericardium. The pericardial cavity lies between the parietal and visceral layers of the serous pericardium.

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 comprised of the auricle of the right atrium (3) and the right and left ventricles (1,2). The right auricle (3) and right ventricle (1) are separated from one another by the coronary (atrioventricular) sulcus or groove which contains, in addition to fat, the right coronary artery (23). The coronary sulcus continues around the heart separating the atria (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 (31).

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 this 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. During contraction of the heart, the apex taps the chest wall at the level of the fifth intercostal space about 3.5 inches (9 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 lean living subject 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 endocardium 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 and leaving 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 cardiac muscle which is responsible for the heart's ability to contract and pump. A fibrous septum separates the musculature of the atria from the ventricles and surrounds the openings of the heart valves. The myocardium of the atria is thin since the work required is minimal. The musculature of the ventricles is much thicker than that of the atria. The left ventricle is considerably thicker than the right since the left must pump the blood to the entire body while the right ventricle must pump only to the lungs. The musculature of the ventricles is made up of spiral layers of muscle which encircle the chambers of the heart and have their origin and insertions on the fibrous septum between the atria and ventricles. When the ventricles contract a wringing action results and the ventricular walls come together similar to a squeezing fist and exert pressure on the blood inside.

The outer layer of the heart, the epicardium, is the visceral serous pericardium which was discussed previously. This layer is firmly attached to the myocardium except at the coronary and interventricular sulci where blood vessels and sizable deposits of fat intervene between the epicardium and myocardium.

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 (66) 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. Oxygenated blood (red arrows) from the lungs returns to the left atrium (95) of the heart through the pulmonary veins (50,51). After passing through the bicuspid (mitral) valve (94) into the left ventricle (2), the oxygenated blood is pumped through the aortic valve (80) to be distributed throughout the body by the aorta (5) and its branches (Figure 2).

BLOOD SUPPLY OF THE HEART

Coronary Arteries

An abundant supply of oxygenated blood reaches the muscle fibers of the myocardium by 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 pouch-like dilatations in the aortic wall called aortic sinuses, one opposite each of the three cusps of the valve (104-106). The coronary arteries arise from the aortic sinuses opposite the left and right cusps (105,104). On the DON JAKE SAUNDERS HEART MODEL, the orifice of the left coronary artery is the red dot immediately above the left cusp (105). The orifice of the right coronary artery is shown on the part of the aorta which is opened with the anterior wall of the right atrium (upper left door).

The right coronary artery (23) passes between the root of the pulmonary trunk (6) and the auricle of the right atrium (3) and then runs downward and to the right in the coronary sulcus. After turning the right margin of the heart it runs to the left in the posterior

INDEX

Numbers in bold face type refer to the key code numbers.

DON JAKE SAUNDERS HEART MODEL
Numerical Key Code

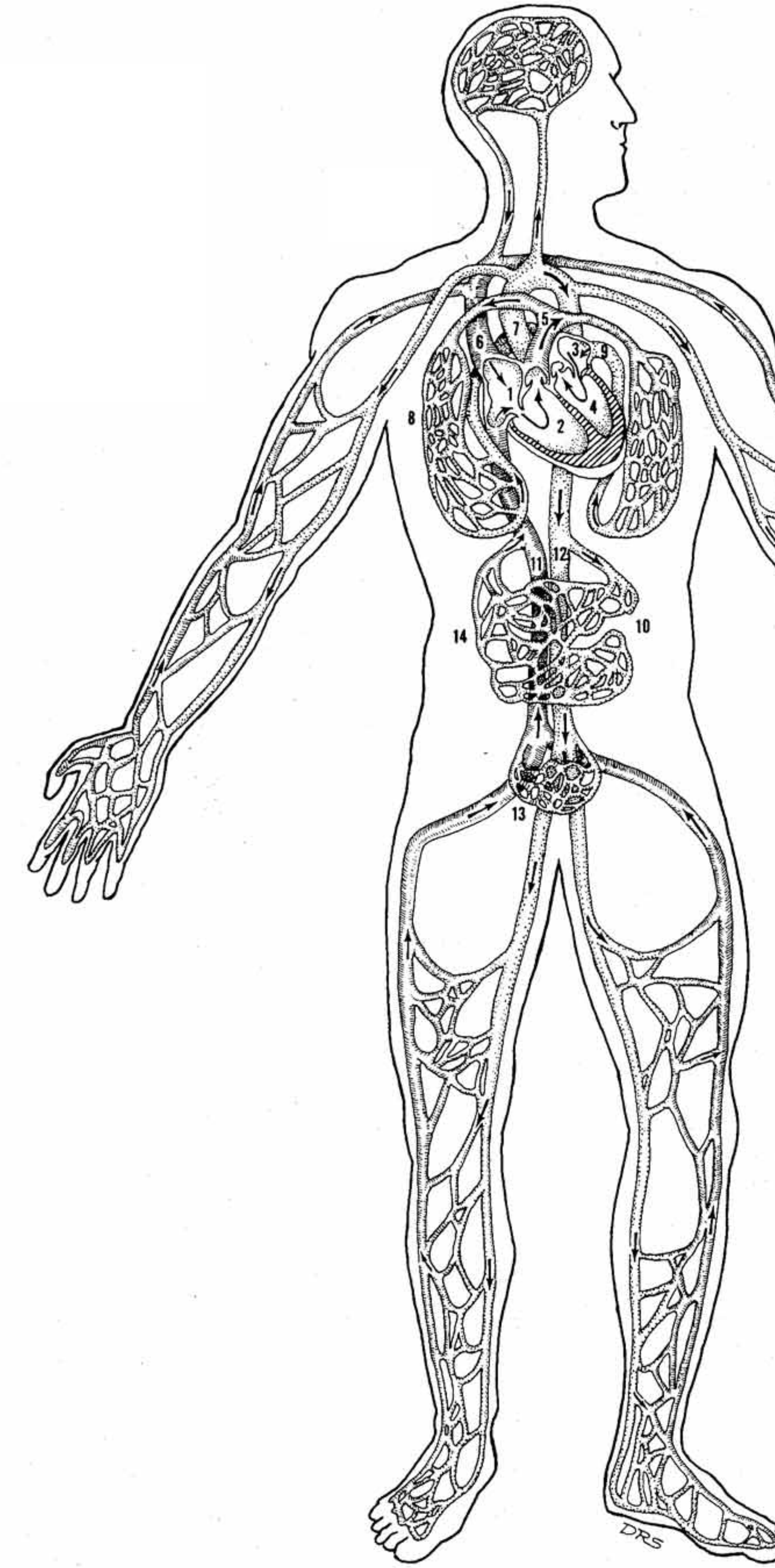
1. Right Ventricle
2. Left Ventricle
3. Auricle of Right Atrium
4. Auricle of Left Atrium
5. Aorta
6. Pulmonary Trunk
7. Brachiocephalic (Innominate) Vein
8. Superior Vena Cava
9. Brachiocephalic Trunk (Innominate Artery)
10. Common Carotid Artery
11. Subclavian Artery
12. Left Pulmonary Artery
13. Ligamentum Arteriosum
14. Thyrocervical Trunk
15. External Jugular Vein
16. Subclavian Vein
17. Internal Jugular Vein
18. Internal Thoracic Artery
19. Internal Thoracic Vein
20. Inferior Thyroid Vein
21. Vertebral Artery
22. Vertebral Vein
23. Right Coronary Artery
24. Anterior Right Atrial Branch (Right Coronary Artery)
25. Superior Vena Caval (Nodal) Branch (Right Atrial Artery)
26. Right Marginal Artery (Right Coronary Artery)
27. Posterior Interventricular (Posterior Descending) Branch of Right Coronary Artery
28. Left Coronary Artery
29. Circumflex Branch (Left Coronary Artery)
30. Anterior Interventricular (Anterior Descending) Branch of Left Coronary Artery

30A. Diagonal Branch of Anterior Interventricular Artery

31. Great Cardiac Vein
32. Anterior Cardiac Veins
33. Small Cardiac Vein
34. Coronary Sinus
35. Posterior Vein of Left Ventricle
36. Oblique Vein of Left Atrium
37. Middle Cardiac Vein
38. Left Vagus Nerve
39. Right Vagus Nerve
40. Recurrent Laryngeal Nerve (Branch of Left Vagus)
41. Left Vagal Cardiac Nerves
42. Left Sympathetic Cardiac Nerves
43. Right Sympathetic Cardiac Nerves
44. Thoracic Duct
45. Esophagus
46. Trachea
47. Right Bronchus
48. Left Bronchus
49. Right Pulmonary Artery
50. Left Pulmonary Veins
51. Right Pulmonary Veins
52. Azygos Vein
53. Superior Intercostal Vein
54. Posterior Intercostal Arteries
55. Tracheal Lymph Nodes
56. Inferior Tracheobronchial Lymph Nodes
57. Internal Jugular Lymph Nodes
58. Anterior Mediastinal Lymph Nodes
59. Atrioventricular Bundle (of His)
60. Inferior Vena Cava
61. Supraventricular Crest
62. Septal Band
63. Moderator Band
64. Trabeculae Carneae
65. Conus Arteriosus (Infundibulum)
66. Pulmonic Valve
67. Right Bundle Branch
68. Posterior Papillary Muscle
69. Anterior Papillary Muscle
70. Septal (Medial) Papillary Muscle
71. Parietal Band
72. Anterior Cusp - Tricuspid Valve
73. Septal (Medial) Cusp - Tricuspid Valve
74. Posterior Cusp - Tricuspid Valve
75. Chordae Tendineae
76. Anterior Papillary Muscle
77. Posterior Papillary Muscle
78. Anterior Cusp - Bicuspid Valve
79. Posterior Cusp - Bicuspid Valve
80. Aortic Valve
81. Fossa Ovalis
82. Valve of Inferior Vena Cava
83. Orifice of Coronary Sinus
84. Crista Terminalis
85. Taenia Sagittalis
86. Sinoatrial (SA) Node
87. Bachmann's Bundle
88. Posterior Internodal Tract
89. Pectinate Muscle
90. Anterior Internodal Tract
91. Middle Internodal Tract
92. Valve of Foramen Ovale
93. Tricuspid Valve
94. Bicuspid (Mitral) Valve
95. Left Atrium
96. Right Atrium
97. Muscular Interventricular Septum
98. Membranous Septum (Interventricular Part)
99. Membranous Septum (Atrioventricular Part)
100. Atrioventricular (AV) Node
101. Anterior Cusp - Pulmonic Valve
102. Right Cusp - Pulmonic Valve
103. Left Cusp - Pulmonic Valve
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



1. Right Atrium
2. Right Ventricle
3. Left Atrium
4. Left Ventricle
5. Pulmonary Artery
6. Superior Vena Cava
7. Aorta
8. Pulmonary Capillaries
9. Pulmonary Vein
10. Arteries of Digestive System
11. Inferior Vena Cava
12. Descending Aorta
13. Capillaries of the Urogenital System
14. Veins of Digestive System

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 anastomoses 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 atrial artery (24) is of great importance. This branch is the superior vena caval branch (nodal artery) (25) which supplies blood to the sinoatrial node (86). The second major branch of the coronary artery is the right marginal artery (26) 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 ventricles as well as part of the interventricular septum (97).

The left coronary artery (28) arises from behind the left aortic cusp (105) and passes between the pulmonary trunk (6) and the auricle of the left atrium (4) to reach the coronary (atrioventricular) sulcus. Upon reaching the sulcus, the left coronary artery (28) branches into the anterior interventricular (or anterior descending) artery (30) and the circumflex artery (29). The anterior interventricular artery (30) descends in the anterior interventricular sulcus and in many subjects turns around the apex of the heart and runs a variable distance in the posterior interventricular sulcus. This artery and its branches (30A) supply the myocardium of both ventricles and part of the interventricular septum (97) and also anastomoses with the posterior interventricular artery (27). The circumflex branch (29) is the continuation of the left coronary artery (28) in the coronary sulcus. It anastomoses 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 atrium. Left marginal branches of the circumflex (not numbered on the model) extend along the left border of the heart.

The anastomoses between the branches of the coronary arteries are at the level of the arterioles. These small branches of the coronary arteries are functionally end-arteries, since the anastomoses through them are not adequate to maintain sufficient collateral circulation if a large branch of a coronary artery were to suddenly become obstructed. If, on the other hand, the obstruction developed gradually, the small vessels of the anastomoses 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 sulci 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 portion 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 83 inside the right atrium).

The main tributaries of the coronary sinus are:
1. The great cardiac vein (31) 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 artery (30) and the circumflex branch of the left coronary 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 termination. The middle cardiac vein parallels the posterior 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 (26) and then the right coronary artery (23) after it reaches the coronary (atrioventricular) sulcus.
4. The posterior vein of the left ventricle (35) 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 atrium (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 ventricle (1), cross the coronary sulcus above the right coronary artery (23) and open directly into the right atrium. The venae cordis minimae (smallest cardiac or Thebesian veins) are minute veins in the myocardium which open directly into the heart chambers. 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 muscular walls of each chamber — the atria have considerably thinner walls than the ventricles. This difference reflects the fact that the atria act as receiving chambers of the heart and the ventricles as the pumping chambers.

Each of the four chambers has its own characteristic appearance, structures and related vessels.

Right Atrium

The thin walled right atrium receives deoxygenated blood from the body by way of the vena cavae (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 vertically 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

Internal Right Atrium

59. Atrioventricular Bundle (of His)
81. Fossa Ovalis
82. Valve of Inferior Vena Cava
83. Orifice of Coronary Sinus
84. Crista Terminalis
85. Taenia Sagittalis
86. Sinoatrial (SA) Node
87. Bachmann's Bundle
88. Posterior Internodal Tract
89. Pectinate Muscle
90. Anterior Internodal Tract
91. Middle Internodal Tract
93. Tricuspid Valve
96. Right Atrium
99. Membranous Septum (Atrioventricular Part)
100. Atrioventricular (AV) Node

Internal Right Ventricle

61. Supraventricular Crest
62. Septal Band
63. Moderator Band
64. Trabeculae Carneae
65. Conus Arteriosus (Infundibulum)
66. Pulmonic Valve
67. Right Bundle Branch
68. Posterior Papillary Muscle
69. Anterior Papillary Muscle
70. Septal (Medial) Papillary Muscle
71. Parietal Band
72. Anterior Cusp - Tricuspid Valve
73. Septal (Medial) Cusp - Tricuspid Valve
74. Posterior Cusp - Tricuspid Valve
75. Chordae Tendineae
97. Muscular Interventricular Septum

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

Internal Left Atrium

50. Left Pulmonary Veins
51. Right Pulmonary Veins
89. Pectinate Muscle
92. Valve of Foramen Ovale
94. Bicuspid (Mitral) Valve
95. Left Atrium

Internal Left Ventricle

64. Trabeculae Carneae
76. Anterior Papillary Muscle
77. Posterior Papillary Muscle
78. Anterior Cusp - Bicuspid Valve
79. Posterior Cusp - Bicuspid Valve
80. Aortic Valve
98. 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

DON JAKE SAUNDERS HEART MODEL
Regional Key Code

External

External Anterior Aspect
1. Right Ventricle
2. Left Ventricle
3. Auricle of Right Atrium
4. Auricle of Left Atrium
5. Aorta
6. Pulmonary Trunk
7. Brachiocephalic (Innominate) Veins
8. Superior Vena Cava
9. Brachiocephalic Trunk (Innominate Artery)
10. Common Carotid Artery
11. Subclavian Artery
12. Left Pulmonary Artery
13. Ligamentum Arteriosum
15. External Jugular Vein
16. Subclavian Vein
17. Internal Jugular Vein
18. Internal Thoracic Artery
19. Internal Thoracic Vein
20. Inferior Thyroid Vein
23. Right Coronary Artery
24. Anterior Right Atrial Branch (Right Coronary Artery)
26. Right Marginal Artery (Right Coronary Artery)
28. Left Coronary Artery
29. Circumflex Branch (Left Coronary Artery)
30. Anterior Interventricular (Anterior Descending) Branch of Left Coronary Artery

30A. Diagonal Branch of Anterior Interventricular Artery

31. Great Cardiac Vein
32. Anterior Cardiac Veins
38. Left Vagus Nerve
40. Recurrent Laryngeal Nerve (Branch of Left Vagus)
41. Left Vagal Cardiac Nerves
42. Left Sympathetic Cardiac Nerves
43. Right Sympathetic Cardiac Nerves
46. Trachea
53. Superior Intercostal Vein
57. Internal Jugular Lymph Nodes
58. Anterior Mediastinal Lymph Nodes

External Posterior Aspect
14. Thyrocervical Trunk
21. Vertebral Artery
22. Vertebral Vein
25. Superior Vena Caval (Nodal) Branch (Right Atrial Artery)
39. Right Vagus Nerve
44. Thoracic Duct
45. Esophagus
47. Right Bronchus
48. Left Bronchus
49. Right Pulmonary Artery
50. Left Pulmonary Veins
51. Right Pulmonary Veins
52. Azygos Vein
54. Posterior Intercostal Arteries
55. Tracheal Lymph Nodes
56. Inferior Tracheobronchial Lymph Nodes
60. Inferior Vena Cava
95. Left Atrium
96. Right Atrium

External Inferior Aspect
1. Right Ventricle
2. Left Ventricle
27. Posterior Interventricular (Posterior Descending) Branch of Right Coronary Artery
33. Small Cardiac Vein
34. Coronary Sinus
35. Posterior Vein of Left Ventricle
36. Oblique Vein of Left Atrium
37. Middle Cardiac Vein

drains into the right atium 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 rudementary valve, the valve of the inferior vena cava (or Eustachian valve) (82), formed by a crescentric fold on the anterior margin of the orifice. This valve is more prominent during intrauterine life where it serves to direct the blood from the inferior vena cava into the left atrium through an opening, the foramen ovale, in the interatrial septum. In this manner, blood bypasses the non-functioning lungs. The circulation of blood through the fetal heart is covered in more detail below. The valve of the inferior vena cava (82) has no known function in the adult heart. The foramen ovale normally closes shortly after birth and becomes the fossa ovalis (81), and oval depression in the lower part of the septal wall. The membranous part of the atrioventricular septum (99) extends slightly above the attachment of the septal (medial) cusp (73) of the tricuspid valve where it forms part of the medial wall of the right atrium. More will be said about the interventricular septum later.

The right atrium can be divided into two parts. The posterior part into which the superior and inferior vena cavae enter has smooth walls and is, developmentally, a continuation of these vessels. The anterior part of the right atrium is the original embryonic right atrium and its walls consist of parallel muscle ridges called pectinate muscles (89). The two parts of the right atrium are separated from one another by a smooth muscular ridge, the crista terminalis (84). The pectinate muscles (89) run forward from the crista terminalis (84) across the lateral and anterior walls of the atrium, angling toward the tricuspid valve (93). The upper portion of the atrium contains a conical muscular outpouching called the auricle (3). Externally the auricle lies in front of the origin of the aorta (5) and covers the first portion of the right coronary artery (23). Internally the wall of the auricle is covered with pectinate muscles (89). A somewhat larger pectinate muscle, the taenia sagittales (85), originates from the crista terminalis and extends into the auricle.

Two important structures associated with the conduction system of the heart are located in the wall of the right atrium. The sinoatrial (SA) node (86) is located at the upper end of the crista terminalis (84) at the junction of the atrium proper and the superior vena cava (8). In an actual specimen, the node would not be visible since it is located within the myocardium. Electrical impulses which cause the heart to contract rhythmically, originate from the SA node which is often referred to as the "pacemaker." The sinus impulse spreads to the right atrium directly from the SA node. Tracts of modified cardiac muscle cells (87, 88, 90, 91) carry the sinus impulse to the left atrium and to the atrioventricular (AV) node (100). Bachmann's bundle (87) transmits these impulses to the left ventricle while three internodal tracts (88, 90, 91) transmit them to the AV node (100) which is located in the interatrial septum just above the orifice of the coronary sinus (83). The atrioventricular bundle (of His) (59) transmits the impulse from the AV node through the fibrous atrioventricular septum into the musculature of the interventricular septum (97). The conduction system of the heart is covered in more detail below.

Right Ventricle

The outer wall of the right ventricle is much thicker than the walls of the atria but thinner than those of the left ventricle. In cross-section, the right ventricle has a crescent-shaped chamber 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 ventricle. 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 parietal band (71), the supraventricular crest (61), and the septal band (62).

Blood flows from the right atrium into the right ventricle through the right 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 ventricular cavity. Tendinous cords, the chordae tendineae (75), extend from the underside (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 (61) 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 overdistension 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 (67) and left (107) bundle branches in the interventricular 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. Divisions of the right bundle reach the anterior ventricular wall and the base of the anterior papillary muscle (69) through the septomarginal trabecula (moderator band) (63). The divisions break up into a plexus of Purkinje fibers (108) which pass beneath the endocardium 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 ventricle, 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 infundibulum from the pulmonary trunk. This valve consists 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 (95) of the heart through four pulmonary veins (50,51). 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 (89) are present. A semilunar depression on the septal wall of the left ventricle marks the location of the fossa ovalis (81) of the right atrium. Inferior to this depression is a crescentric 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 (80) is relatively smooth. Two large papillary muscles arise from the anterior (76) and posterior (77) walls and are named accordingly. Chordae tendineae (75) extend from the tips of the papillary muscles to the ventricular surface (underside) of the cusps of the left atrioventricular valve (78,79). The valve is similar in construction and function 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 anterior cusp (78) is located between the aortic and left atrioventricular orifices. The posterior cusp (79) is located behind and to the left of the orifice. The papillary muscles (76,77) are located below the commissures of the valve and chordae tendineae (75) extend from each muscle to the two cusps.

The left bundle branch (107) of the atrioventricular bundle (59) descends immediately beneath the endocardium 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 plexis of Purkinje fibers (108) in the trabeculae carneae (64) and papillary muscles (76,77).

The aortic orifice is guarded by the aortic similunar 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 aorta 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 often 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 septum bulges into the cavity of the right ventricle. On the surface of the heart, the anterior and posterior interventricular grooves or sulci correspond with 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 tricuspid valve, which divides it into anterior and posterior parts. The anterior part separates the two ventricles from each other (membranous interventricular septum) (98). 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 interventricular septum. Such a condition would result in leakage of oxygenated blood from the high pressured 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 atrioventricular groove on the surface of the heart. When visualized with the atria removed, the fibrous skeleton 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 endocardium strengthened by intervening layers of fibrous tissue.

and the bronchus on each side (47,48). Tracheal (paratracheal) lymph nodes (55) lie along each side of the trachea. Lymph vessels from the lungs and bronchi (47,48), the thoracic part of the trachea (46) and esophagus (45) and part of the heart drain into the tracheobronchial and tracheal lymph nodes.

The anterior mediastinal lymph nodes (58), located in the vicinity of the aortic arch (5) and the brachiocephalic veins (7), receive lymph vessels from the pericardium and part of the heart.

Efferent vessels from all of these nodes unite to form a single vessel on each side of the trachea which drains into the left and right bronchomediastinal lymph trunk. The right trunk may join the right lymphatic duct and the left may join the thoracic duct, but usually they drain directly into the junction of the internal jugular (17) and subclavian (16) veins.

The internal jugular lymph nodes (57) are located along the internal jugular vein (17). On the right side they usually drain into the right lymphatic duct, and on the left into the thoracic duct.

clavian artery and runs downward, behind the brachiocephalic vein (7). Below the level of the first rib, the artery descends vertically about 1 cm lateral to the margin of the sternum where it supplies the anterior wall of the body from the clavicle to the umbilicus. The thyrocervical trunk (14) is a short thick stem which divides almost immediately into three main branches which supply the thyroid gland (inferior thyroid artery) and the muscles of the shoulder and scapula (suprascapular and transverse cervical arteries).

The diameter of the aortic arch is about equal to that of the ascending aorta (3 cm) until after the left subclavian artery branches off. At this point the diameter narrows to about 2 cm.

The descending portion of the thoracic aorta is continuous with the aortic arch, and at first it lies to the left of the vertebral column. As it descends it approaches the medial plane and terminates by passing through the diaphragm in front of the vertebral column. The posterior intercostal arteries (54) are branches from the posterior surface of the descending aorta that are distributed to the intercostal muscles and the posterior and lateral thoracic wall.

THE SUPERIOR VENA CAVA AND ITS TRIBUTARIES

Venous blood from the head and neck, the upper limbs, and thoracic wall returns to the heart through the superior vena cava (8). This large vessel is formed by the union of the left and right brachiocephalic (innominate) veins (7) at the level of the first costal cartilage. It descends on the right side of the ascending aorta (5) and ends in the upper part of the right atrium. The azygos vein (52), which receives venous blood from the posterior and lateral thoracic wall, enters the superior vena cava just above the structures of the root of the right lung [right bronchus (47), right pulmonary artery (49) and vein (51)].

The brachiocephalic veins (7) are formed in the base of the neck by the union of the internal jugular (17) and subclavian (16) veins. The right brachiocephalic vein is short and descends almost vertically while the left is considerably longer and runs downward and to the right.

The internal jugular vein (17) has its origin at the base of the skull and receives blood from the brain, face, and neck. The subclavian veins (16) accompany the subclavian arteries (11), and are continuous with the axillary veins which drain the upper limbs. The external jugular vein (15) receives tributaries from the scalp, face and neck and joins the subclavian vein (16) just before that vein joins the internal jugular (17) to form the brachiocephalic vein (7).

Each brachiocephalic vein receives a vertebral (22) and internal thoracic (19) vein. The vertebral vein (22) opens into the upper and posterior part of the brachiocephalic vein (7). The internal thoracic vein (19) accompanies the artery (18) and receives venous blood from the anterior thoracic body wall.

In addition to the vertebral and internal thoracic veins, the left brachiocephalic vein receives tributaries which drain the second and third intercostal spaces, the superior intercostal vein (53), and the thyroid gland, the inferior thyroid vein (20).

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, since the thoracic cavity contains main lymph channels and numerous lymph nodes, a brief discussion is appropriate.

Cells of the body get their nutritive 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 reenter the capillaries, however, the large protein molecules do not. It is the function of 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 JAKE 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 and larger lymphatic vessels which eventually reach the regional lymph nodes. Lymphatic vessels carry the lymph from one lymph node to another. Eventually the lymph vessels join together forming lymphatic trunks which in turn join to form lymphatic ducts. The ducts empty into the venous system 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 neck it turns laterally to the left behind the common carotid artery (10) and internal jugular vein (17). 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.

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 JAKE SAUNDERS HEART MODEL.

Tracheobronchial lymph nodes are located in the region of the tracheal bifurcation. The inferior tracheobronchial nodes (56) are located in the angle below the bifurcation. The superior tracheobronchial nodes which are not numbered on the model, are in the angle between the trachea (46)

The DON JAKE 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 (80) valves are closed.

Atrioventricular Valves

The right atrioventricular valve (93) consists of three cusps or 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 bishop's mitre.

The cusps are continuous at their attachment with the fibrous skeleton around each orifice. Since the commissure between the cusps varies in depth, but never reaches the fibrous ring of the orifice, the cusps are only incompletely separated from each other. The chordae tendinae (75) extend from the underside (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 interventricular septum. The posterior cusp (74) which is usually the smallest, is attached along the posterior-inferior border of the orifice.

The three cusps of the tricuspid valve do not have individual papillary muscles. The large anterior papillary muscle (69) sends chordae tendineae (75) to both the anterior (72) and posterior (74) cusps. The posterior papillary muscle (68) sends its chordae tendineae to the septal (73) and the posterior (74) cusps. Chordae tendineae from the septal 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 biscuspid or mitral valve (94) consists of anterior (78) and posterior (79) cusps which are larger, thicker and stronger than those of the tricuspid valve. The anterior cusp (78) is located anterior and to the right between the aortic and left atrioventricular orifices. The posterior cusp (79) is located posterior and to the left of the atrioventricular orifice. There are usually two papillary muscles in the left ventricle, an anterior (76) located on the anterior wall and a posterior (77) on the posterior (inferior) wall. These papillary muscles occasionally show doubling as demonstrated by the posterior papillary muscle (77) in the DON JAKE 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 the chordae tendineae are tightened thus holding the cusps in position and preventing their being everted into the atria. Dysfunction of a papillary muscle or rupture of a chordae tendineae may affect the support of the valve cusp(s) and produce regurgitation of blood into the atrium. Closure of the atrioventricular valves causes the first heart sound: the "lub" of "lub-dub."

Aortic and Pulmonic Valves

The pulmonic (66) and aortic (80) 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-

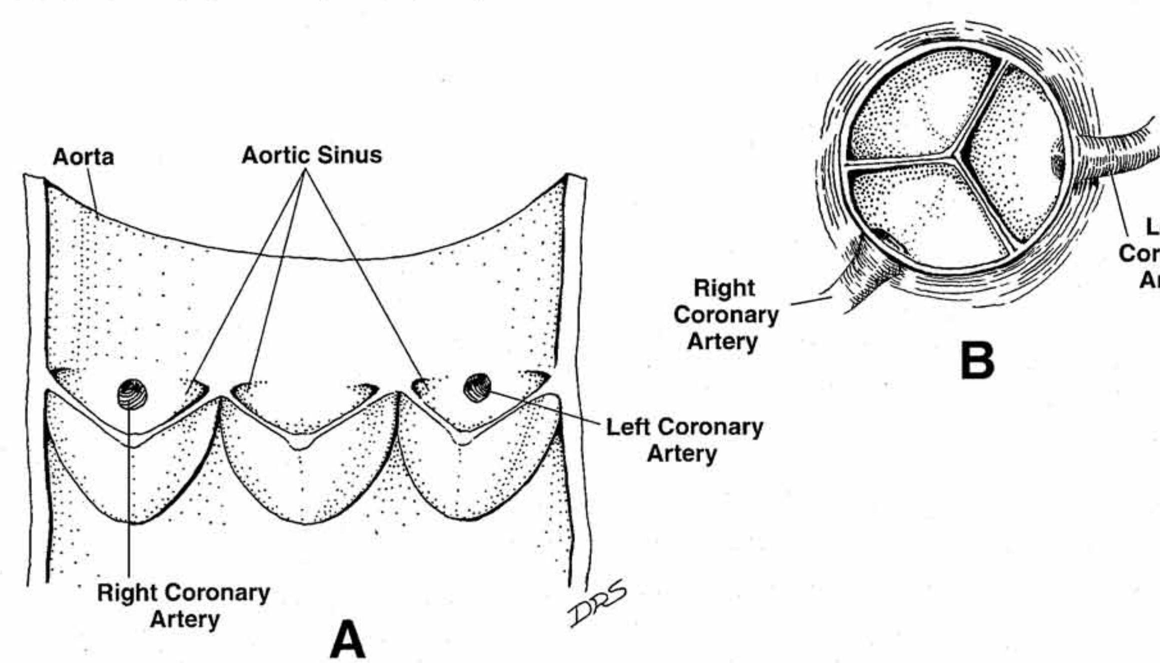


Fig. 3. The aortic (semilunar) valve. (a) The aorta has been opened longitudinally to show the semilunar valves. (b) The aortic valve in the closed position as seen from above.

pended from the base of the wall of the aorta and pulmonary trunk. The free inner border, the lunulae, of each cusp projects into the lumen of the vessel. Behind each cusp the vessel wall bulges outward forming a pouch-like dilatation known as pulmonary and aortic sinuses or sinuses of Valsalva.

The pulmonic cusps are referred to as anterior (101), right (102) and left (103). The cusps of the aortic valve are designated right (104), left (105) and posterior (106). The left and right coronary arteries arise from the aortic sinuses behind the left and right aortic cusps, respectively, and these cusps are often referred to as "coronary" cusps. The posterior cusp, which is not associated with a coronary artery, is the "non-coronary" cusp.

When the ventricles contract the cusps of the aortic and pulmonic valves are pressed against the walls of the vessels permitting the blood to pass freely. During ventricular relaxation, the blood in the aorta and pulmonary trunk tends to flow toward the ventricles where the pressure is lower. This back flow of blood fills the pocket-like cusps of the valves thus closing them tightly and preventing the blood from returning to the ventricles. The closing of the aortic and pulmonic valves causes the second heart sound: the "dub" of "lub-dub." Failure of the cusps to close properly due to valvular disease results in regurgitation into the ventricles and a heart murmur results.

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 serves to change the force or frequency of the beat according to the physiological needs of the individual. Even after the heart has been removed from the body and all the nerves to it have been cut, it will continue to beat since the beat is generated within the heart and the nerves have only a regulatory influence.

The coordinated contraction of the artia and ventricles which results in the effective pumping of blood requires a system which distributes nervous impulses in the proper sequence and at the proper time. The sequencing and timing are performed by the specialized group of cardiac muscle fibers which make up the conduction system of the heart. This system is composed of the sinoatrial (SA) node (86), Bachmann's bundle (87), the internodal tracts (88, 90, 91), the atrioventricular (AV) node (100), the atrioventricular bundle (of His) (59), the bundle branches (67, 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 (84) near the opening of the superior vena cava (8). The node is composed of interwoven strips of modified muscle and there are numerous nerve endings from the autonomic nervous system. The electrical impulses that cause the heart to contract rhythmically originate from the SA node which is, therefore, referred to as the "pacemaker" of the heart. The impulse spreads 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 (100) by internodal tracts (88,90,91). The anterior internodal tract (90) and Bachmann's bundle (87) are responsible for the spread of the sinus impulse to the left atrium. The spread of the impulse through the myocardium of the atrial walls takes about 0.1 second and both atria contract almost 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 part of the atrial septum just above the attachment of the septal cusp (73) of the tricuspid valve. The structure of the AV node is similar to that of the SA node in that it is composed of a meshwork of modified cardiac muscle fibers. The fibers converge at the anterior and inferior margin of the node and form the atrioventricular (AV) bundle (of His) (59) which passes through an opening in the fibrous nonconducting 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 at 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 part of the septum (98). At the crest of the 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 descend beneath the endocardium towards the apex on the right side of the ventricular septum. Divisions of the right bundle branch reach the anterior right ventricular wall and the base of the anterior papillary muscle (69) through the septomarginal trabecula (moderator band) (63). The divisions break into a plexus of Purkinje fibers (108) (named in honor of the anatomist who first described them) which pass beneath the endocardium to the greater part of the right ventricle where they end by becoming continuous with the myocardial fibers.

The left bundle branch (107) is a sheet of fibers which divides into major anterior and posterior divisions. The divisions course just beneath the endocardium and rapidly fan out in all directions and form a plexus of Purkinje fibers (108) in the trabeculae carneae (64) and papillary muscles (76,77). There is no septomarginal trabecula (moderator band) in the left ventricle. The Purkinje fibers taper down to become continuous with the myocardial fibers.

Upon reaching the AV node, the impulse is delayed about 0.11 second before being transmitted rapidly through the AV bundle and the Purkinje fiber

HEART SOUNDS

During the cardiac cycle, sounds which may be heard with a stethoscope or by placing the ear close to the chest, emanate from the heart (Figure 6). It is easy to detect two distinct normal heart sounds which resemble the sound "lub-dub." The "lub" is called the first heart sound and the "dub" the second sound. The first sound is caused by the closure of the AV valves when the ventricles first contract. The rapid closing of the valves prevents backflow from the ventricles into the atria and creates vibrations that are transmitted through the chest to be heard as the first heart sound, the "lub" sound. Immediately after the ventricles have pumped their contents into the aorta and pulmonary trunk, ventricular relaxation permits blood to flow backwards from the vessels into the ventricles. This backflow causes the aortic and pulmonic valves to close suddenly creating the second heart sound, the "dub" sound. Thus 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 too 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 turbulance in the blood as it flows through the valves. Such turbulance may be due to rapid blood flow through narrowed and roughened valves (stenosis). It also occurs when valvular disease prevents adequate closure of the valves and the blood regurgitates back through the partially closed valves.

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

Murmurs, which are the result of valves not closing adequately, will occur during systole if the AV valves are involved and during diastole in the case of the pulmonic or aortic valve. Murmurs caused by a narrowing of the valve orifice (stenosis) will occur during diastole if the AV valves are affected and during systole in the case of the pulmonic and aortic valves.

A murmur during the interval between "dub" and "lub" as, for example, "lub-dub"/murmur/"lub-dub," would occur during diastole. By moving the stethoscope about on the chest, the defective valve could be located. Involvement of one of the AV valves would indicate possible stenosis. If the pulmonic or aortic valves were responsible, they are probably permitting blood to regurgitate into the atria during diastole.

THE AORTA AND ITS BRANCHES

The aorta (5) is the largest artery in the body and supplies oxygenated blood to the systemic arterial system. For descriptive purposes the thoracic portion of the aorta 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 pulmonary trunk (6) and by the auricle of the right atrium (3). The diameter of the ascending aorta is about 3 cm. There are three pouch-like dilatations, the aortic sinuses, one opposite each cusp of the aortic semilunar valve, at the origin of the aorta. The left and right coronary arteries (23,28) are the only branches of th ascending aorta and arise in the left and right sinuses. The orifices of the coronary arteries lie behind the cusps of the aortic valve and the blood can enter them only during ventricular relaxation (diastole). The ascending aorta extends superiorly for about 5 cm where it is continuous with the aortic arch.

The aortic arch is directed at first upward, backward and to the left and then runs downward along the left side of the trachea and becomes continuous with the descending aorta. 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 extends upward and to the right and divides into the right common carotid (10) 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 (46). The left subclavian artery (11), the third branch off the arch, runs superiorly and to the left to enter the base of the neck.

Although the left and right common carotid and subclavian arteries arise differently, they have the same distribution on the two sides of the body. The common carotid arteries course upward in the neck along the trachea. At a level more superior than is shown on the model, the common carotids give off branches which are the major vascular supply to the head and neck.

The subclavian arteries course upward and laterally to arch above the clavicle in the base of the neck. They then run laterally and downward over the first rib. At the lateral border of the first rib, the subclavian arteries become the axillary arteries and the major vascular supply to the upper limb. The origins of three important branches of the subclavian artery are shown on the DON JAKE SAUNDERS HEART MODEL. The vertebral artery (21) runs upward through the transverse foramina of the upper six cervical vertebrae and enters the foramen magnum. In its course it gives branches to some neck muscles, vertebrae, the spinal cord and the brain. The internal thoracic artery (18) arises from the inferior part of the sub-

ELECTROCARDIOGRAPHY

The electrical impulse which passes through the conduction system of the heart, spreads 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 verticle lines indicate time in seconds and horizontal lines, amplitude in millivolts. The "P wave" is caused by the impulse spreading over the atria. The "QRS complex" corresponds to the impulse passing through the ventricles. The "T wave" is caused by the reestablishment of the original electrical properties of the ventricular muscle cells.

The shape of the waves depends on the site of the recording electrodes. The particular arrangement of each two electrode is termed a "lead." Routine clinical electrocardiography consists of recording from twelve leads: three standard limb leads (I,II,III), six precordial (or chest) leads (V_1, V_2, etc.) and three unipolar or augmented, limb leads (aV_F, aV_L, aV_R). Since heart disease is generally accompanied by abnormal electrical events, the electrocardiogram has developed into one of the most useful tools in medicine.

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" (Figure 6). The periods of systole and diastole can be noted from the electrocardiogram or from the heart sounds. Systole begins with the QRS wave and ends with the T wave or it 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.

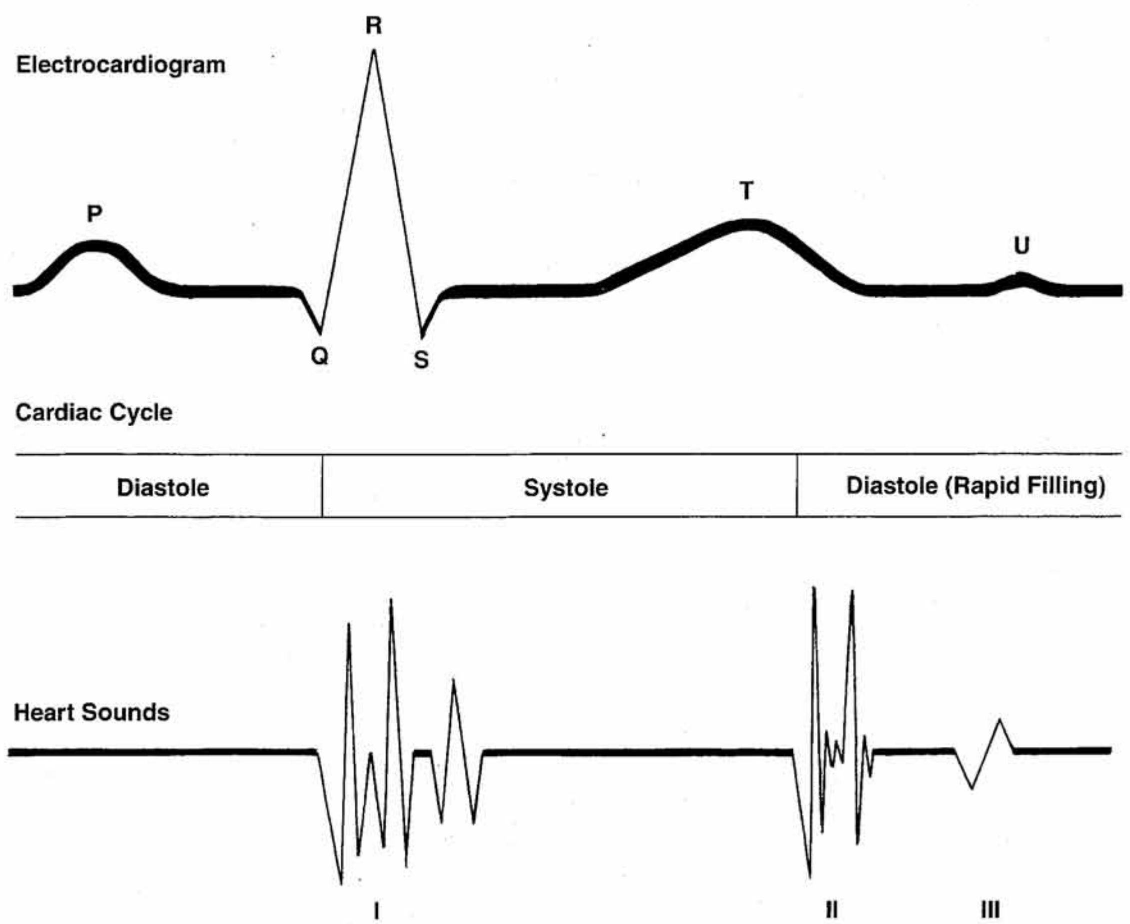


Fig. 6. The cardiac cycle correlated with ECG and heart sounds.

plexus. Once the cardiac impulse has reached the ends of the Purkinje fibers, it is transmitted through the ventricular muscle mass by the ventricular muscle fibers themselves.

INNERVATION OF THE HEART

Modification of the intrinsic rhythmic beat of the heart in response to the changing physiological needs of the body is produced by the cardiac nerves of the autonomic nervous system. The sympathetic division of this system increases the heart rate and force of contraction and dilates the coronary arteries to make available increase amounts of oxygen and nutrients. The parasympathetic division, on the other hand, slows the heart rate, reduces the force of of contraction and constricts the coronary vessels.

Sympathetic cardiac nerves (42,43) from sympathetic ganglia in the neck and upper thorax, converge in the area between the aortic arch and the point where the trachea (46) divides to form the right (47) and the left (48) bronchi. Here the nerves form a network of interlacing nerves known as the cardiac plexus. The sympathetic nerves pass through the cardiac plexus, along the pulmonary trunk and the aorta to reach the coronary vessels and follow these throughout the heart. In addition to innervating the coronary arteries, the sympathetic neurons innervate both the SA (86) and AV (100) nodes, as well as the myocardium of the atria and ventricles.

The parasympathetic innervation of the heart is from branches of the tenth cranial nerve, the vagus nerve (38,39). The nerve descends in the neck, behind and somewhat between the common carotid artery (10) and the internal jugular vein (17). The vagus on each side of the body sends numerous branches to the cardiac plexus. Cardiac branches from the right vagus (39) pass primarily to the deep portion of the plexus which is not in view on the DON JAKE SAUNDERS HEART MODEL. Cardiac branches from the left vagus (41) pass to both the deep and superficial portions of the cardiac plexus. The left recurrent laryngeal nerve (40) branches from the left vagus (38) as it crosses the arch of the aorta. It hooks under the aortic arch behind the ligamentum arteriosum (13) and ascends into the neck to innervate part of the larynx. Numerous branches from the left recurrent laryngeal nerve (40) are given off to the cardiac plexus under the arch of the aorta. The parasympathetic nerves pass through the cardiac plexus and follow the pulmonary trunk and aorta to reach the heart. These nerves follow the coronary arteries which they innervate, to supply the SA and AV nodes and the atria. It is generally felt that the vagal fibers do not innervate the ventricular myocardium.

FETAL CIRCULATION

During the intrauterine 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 oval opening in the 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 into the aorta. This mixed blood, 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 organs 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 inferior 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 is conveyed to the inactive lungs and returned 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 becomes fibrous structures; the intra-abdominal part of the umbilical arteries become the lateral 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 of the blood that enters the pulmonary trunk through the lungs. The ductus arteriosus obliterates to 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 (92) closes and fuses with the interatrial wall. The fossa ovalis (81) 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.

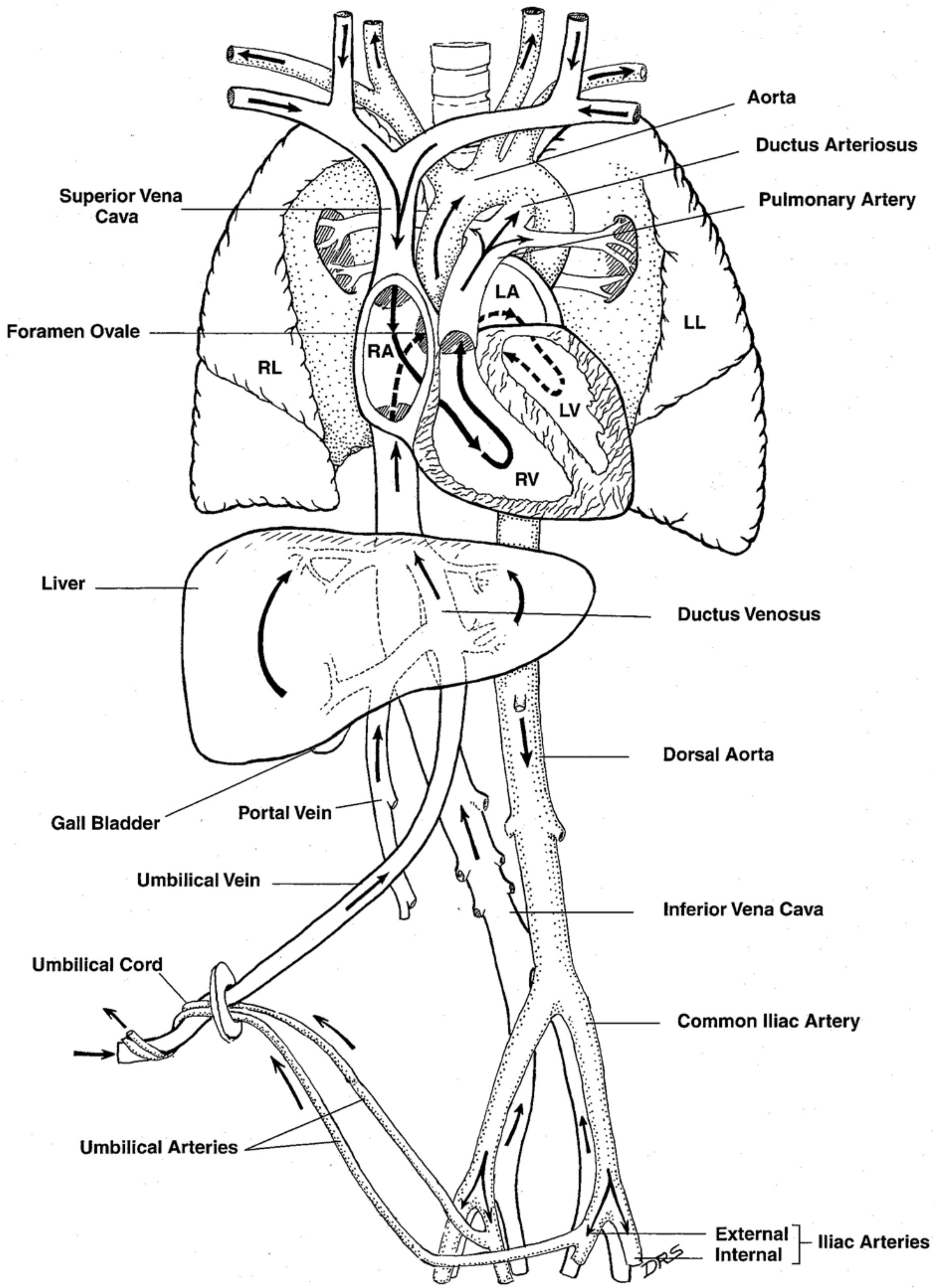


Fig. 4. Circulation of blood in the fetus. The arrows indicate the direction of blood flow. Note the flow through the heart and compare with the flow after birth shown in Figure 5.

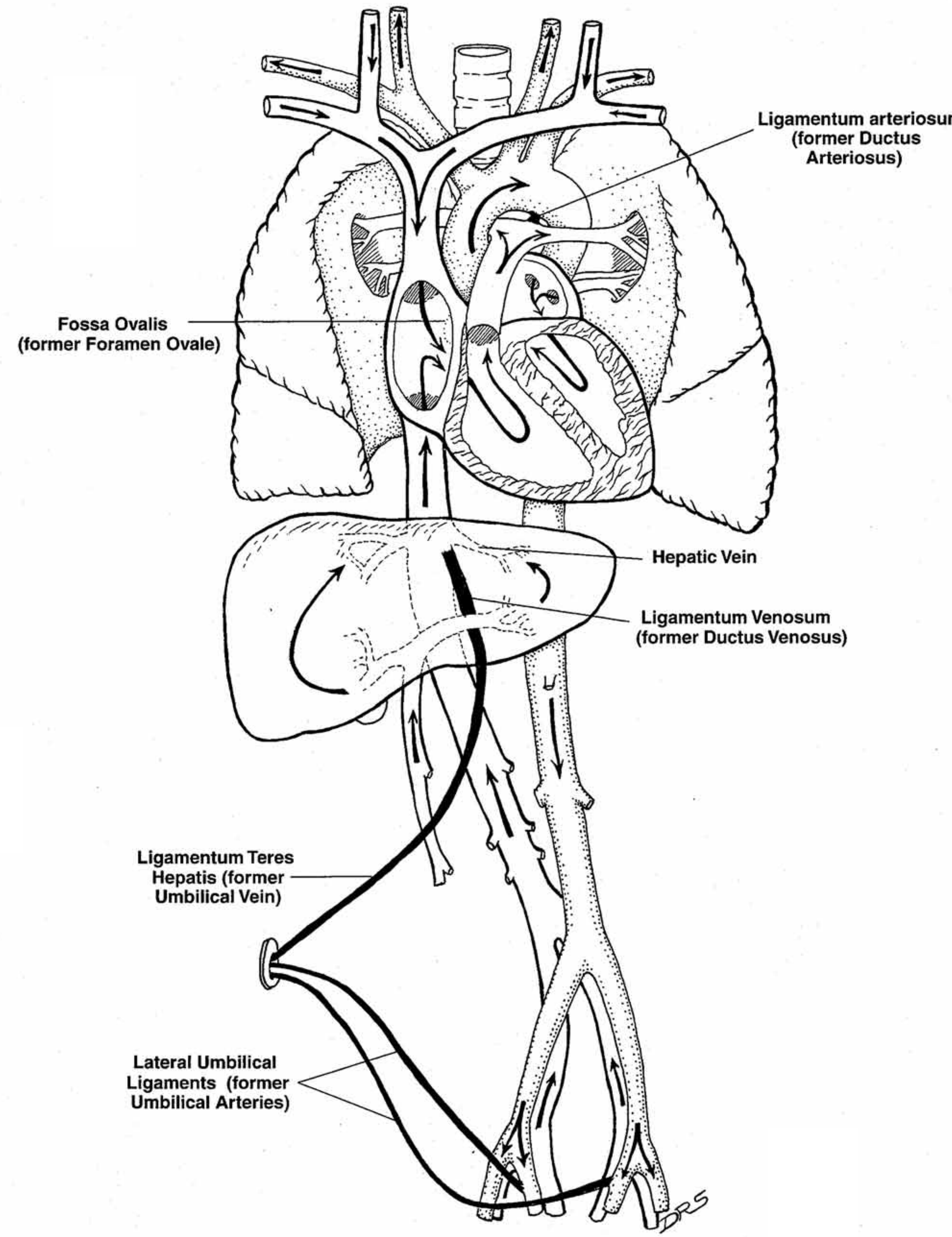


Fig. 5. Circulation of blood after birth. Areas where changes occurred at time of, or shortly after, birth are indicated.