NONINVASIVE TECHNIQUES IN CARDIOLOGY FOR THE NURSE AND TECHNICIAN

A. Benchimol

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To my wife Helena, our sons Nelson and Alex, my beloved father Isaac, my mother Nina, and my sisters and brothers

Foreword

It is a twofold honor to have been privileged to be a technician for a great clinician and teacher and to have been involved in much of the testing that constitutes the material in this book.

Dr. Benchimol has fulfilled a vast need for a concise text dealing with noninvasive studies in cardiology. He has, through his clinical experience, realized the importance of well-trained nurses and technicians and recognized their need for fundamental and practical knowledge. The time and effort put forth by Dr. Benchimol to provide us with such a useful text is a great compliment. It encourages us to strive continually to keep abreast of technological advances.

Bettie J. Massey
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Preface

This book is the result of the author's 15 years of experience in recording and analyzing phonocardiograms, pulse waves such as carotid, jugular venous, and apexcardiograms and other precordial pulsations, echocardiograms, transcutaneous ultrasonic techniques, and vectorcardiograms.

The text is divided into 12 chapters. Chapter 1 describes the anatomy and physiology of the cardiovascular system, which is extremely important in understanding phonocardiographic pulse waves and particularly echocardiography. Chapter 2 is devoted to the description of instrumentation used for phonocardiography, and discusses the basic principles of sound formation, transducers, different types of microphones, amplifiers, and recorders. Emphasis is also placed on the recognition of artifacts. The reader will find basic guidelines for pattern recognition of heart sounds, murmurs, and pulse waves as well as how to measure systolic time intervals and other intervals of the cardiac cycle. In Chapter 3 the field of vectorcardiography is discussed. Instrumentation and lead systems are described in detail. Again emphasis is placed on the importance of recognizing a technically adequate recording as well as artifacts. Comparison is made with the electrocardiogram, although the two techniques differ greatly. Chapter 4 is dedicated to the study of ultrasonic techniques as used in cardiovascular diagnosis. Both echocardiography and the basic Doppler flowmeter techniques are described. The principles of ultrasound, different types of probes, recognition of artifacts, and various types of recorders are described. Chapters 5 through 12 deal with specific disease states. In each of these chapters there is a standard format including recognition of abnormal patterns on phonocardiograms, carotid and jugular venous tracings, apexcardiograms, systolic time intervals, vectorcardiograms, and echocardiograms.

The book is clinically oriented and distinctly dedicated to technicians and nurses working in this field. It may also be useful to medical students and others interested in the technical aspects of noninvasive diagnosis. Areas of major controversy have purposely been avoided. The author does not intend to review all the literature available, but a list of useful references is given at the end of each chapter. A book of this size describing extremely broad issues will suffer in some areas due to the omission of other valuable techniques such as electrocardiography, exercise stress testing, and so forth.

A. B.

Acknowledgments

The author's initial experience that resulted in a lasting interest in cardiovascular diagnosis was obtained under the supervision of Dr. E. Grey Dimond. I am very grateful for his stimulation and support during my training at the University of Kansas School of Medicine, Kansas City, Kansas, and later, as his associate at Scripps Clinic and Research Foundation in La Jolla, California.

Good Samaritan Hospital in Phoenix, Arizona, has provided the necessary support to maintain a research and training program for the past 11 years, and the tracings shown in this book were all recorded there.

The assistance of postgraduate fellows, technicians, nurses, and secretaries who have worked in The Institute for Cardiovascular Diseases at Good Samaritan Hospital, Phoenix, Arizona, has been invaluable. I especially want to thank Bettie J. Massey, Supervisor of the Invasive and Non-Invasive Laboratories, for her outstanding efforts and assistance during the recording of tracings illustrated in this book. Dr. Paul Howard was very helpful during the manuscript preparation. I also want to acknowledge the outstanding efforts of Connie Sheasby, echocardiography technician, and Karen McCullough, phono- and vectorcardiography technician. I am greatly indebted to Sydney Peebles, who prepared all the illustrations and diagrams shown. I want to express my appreciation to Carole Crevier for her outstanding efforts during preparation of the manuscript and for editing and indexing this book and to Frances Maldonado and Bonnie Griner for their great assistance in the transcription, typing, and preparation of each chapter.

A. B.

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Contents

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Basic Anatomy and Physiology of the Cardiovascular System

The heart functions as a pump circulating blood to the rest of the body. It performs this job tirelessly 24 hours a day, 7 days a week, and 365 days of the year. The heart continues this process without deterioration of function and will not fail unless disease alters its course.

In order to gain a close understanding of the subsequent chapters of this book, it would be of benefit to go into some detail about the normal anatomy and physiology of the heart at this time. The heart is a muscular structure that serves as a double pump, circulating blood returning from the body to the lungs for oxygenation and subsequently returning it to the heart for further circulation to the body tissues. The size of the heart is approximately 250–350 grams, or the size of a large fist. It lies in the center of the chest behind the sternum, with the greater portion of its muscular mass slightly to the left of the midline and posteriorly. The heart is protected within the chest by the sternum and rib cage anteriorly and the vertebral column and rib cage posteriorly. There are many other structures within the chest cavity that are in close approximation to the heart. These structures include the lungs, which lie on each side of the heart slightly covering it anteriorly, the esophagus, and the descending thoracic aorta, which lies just posterior to the heart (Fig. 1.1).

Other structures in the chest are protected from the heart's constant muscular contractions by a fibrous sac called the pericardium. The outer portion of this protective membrane (pericardium) is very tough and fibrous in nature. The pericardial membrane is attached to the great vessels entering and leaving the heart, to the diaphragm just below the heart, and to the sternum anteriorly. The inner portion of the pericardium folds around the heart and is adherent to the outer surface of the muscular layers. With this protective membrane, the heart is able to beat freely within the chest cavity without producing undue friction between itself and the other structures around it. Also, the pericardial sac protects the heart from all but the most severe infection that may occur in an adjacent thoracic structure.

The heart lies within this pericardial sac tethered by its attachment to the great vessels and its close attachment to the pericardial membrane. The heart is basi-

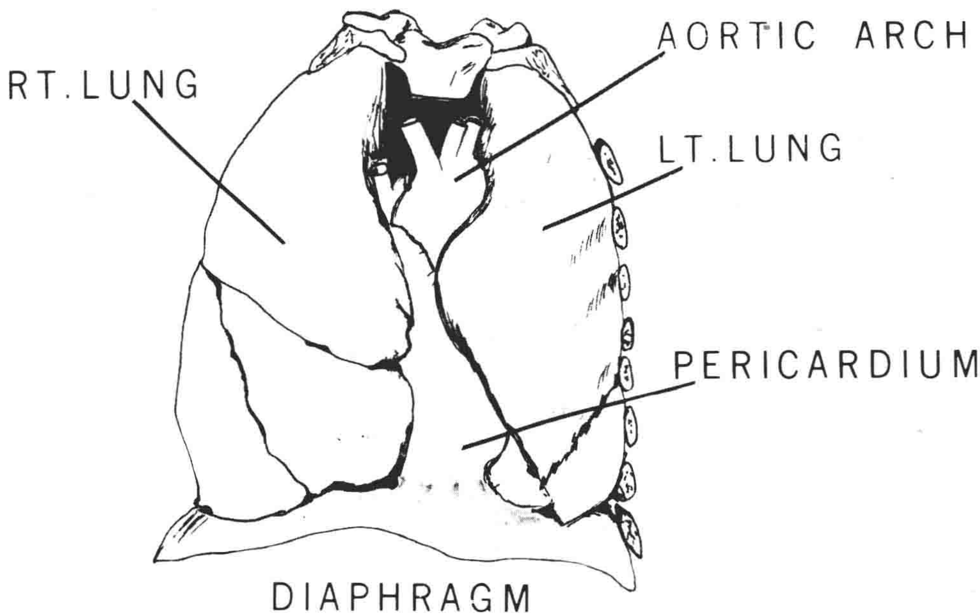

Figure 1.1. Diagrammatic representation of the heart from the frontal view showing the various intracardiac chambers and their relationship to each other.

cally composed of three layers. The outermost layer, the epicardium, is composed of the inner folding of the pericardium, which is in contact with the outer surface of the heart. The second layer, the myocardium, is composed of muscle layers that encompass the heart in a circular fashion. The innermost layer is called the endocardium and it lines the cardiac chambers and covers the valves. The smooth surface of this endocardial layer also extends outside the heart in continuity with the smooth inner surface of the great vessels. The smooth interface of the endocardium is designed to reduce friction on the fragile red blood cells as well as to prevent formation of blood clots within the heart chambers.

Before we look at the heart inside the pericardium, remember that spatial orientation of the heart valves and chambers is important. We talk about the right and left sides of the heart, but their orientation in the chest does not readily compare with that terminology. The heart lies in the center of the chest with the bulk of its muscular mass posterior and to the left. Right heart chambers actually lie anteriorly in the chest, and the left heart chambers lie posteriorly. With this fact in mind, we can look at the heart in detail.

We will now remove the pericardial sac from the heart and view the heart as it is set in the chest from an anterior view (Fig. 1.2). On the outer surface of the heart, or epicardium, one can see small arteries and veins that supply blood to the heart muscle. These vessels, the coronary arteries and veins, are adherent to the outer surface of the heart and have small branches that penetrate the myocardium in order to deliver oxygen and nutrients to the heart muscle. There are two such blood vessels that supply the heart, the right and left coronary arteries, and they have their origin at the very beginning of the ascending aorta. The cardiac veins

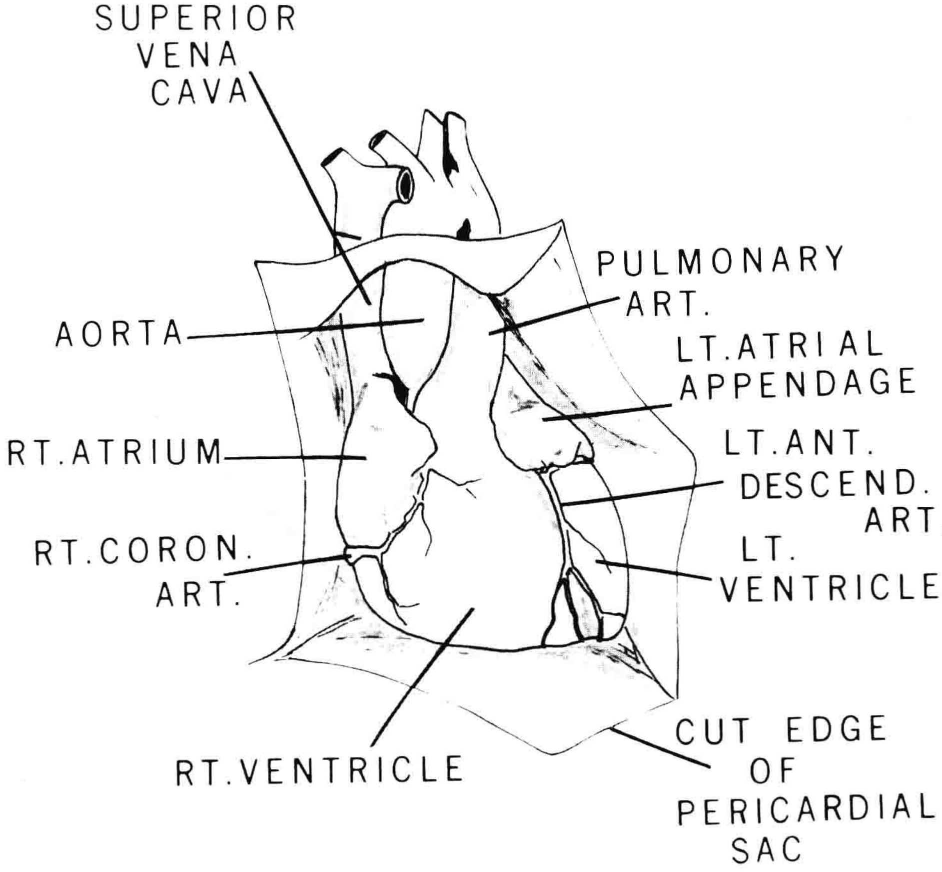

Figure 1.2. Diagrammatic representation of the heart from the frontal view after the pericardial membrane has been removed. The position of the right and left coronary arteries and veins is shown in the epicardial surface of the heart. In addition, note the relationship of the right ventricle, which is the anterior chamber, and the left ventricle, which is the posterior chamber.

are also on the surface of the heart. They empty into what is known as the great cardiac vein, which lies on the posterior surface of the heart and empties into the right atrium at an entrance called the coronary sinus.

Looking at the heart from the frontal position, one can see that the right atrium lies anteriorly and on the right border of the heart. The right atrium receives blood from the upper and lower body through rather large veins called the superior and inferior vena cava, respectively. This blood is low in oxygen as it returns from the body tissues. The blood enters the right atrium and then is circulated to the right ventricle, which occupies the greater portion of the anterior surface of the heart. The right ventricle subsequently pumps the blood into the pulmonary artery, which immediately branches into a right and left vessel in order to transmit this desaturated blood to the lungs for reoxygenation. Blood returning from the lungs, high in oxygen content, enters the left atrium, which is on the posterior surface of the heart and cannot be seen from the front view. From the left atrium, it is then transmitted to the left ventricle where this oxygenated blood is then pumped to the body tissues through the aorta. From the front of the heart, the left ventricle is barely seen and occupies only a small portion of the left border of the heart.

In order to visualize the left atrium and the left ventricle more thoroughly, one must view the heart from a posterior vantage point (Fig. 1.3). In this view, the left atrium can be seen receiving reoxygenated blood from the four pulmonary veins that are coming from the lungs. This blood is then transmitted to the left ventricle, which occupies the greater portion of the heart's posterior surface.

To understand the anatomical configuration of the heart and why certain chambers lie anteriorly and posteriorly, it is of benefit to look at some of the physiologic functions that these chambers possess. Basically speaking, the right and left atria, as their names suggest, are chambers for receiving blood returning to the heart from the body and lungs, respectively. These receiving chambers hold the blood until the pumping chambers (right and left ventricles) have relaxed from their contractions and are able to accept a new volume for ejection to the lungs and body. The atria, then, do not have thick muscular walls; as a result, they function as receiving and filling chambers for the more powerful ventricles. The ventricles,

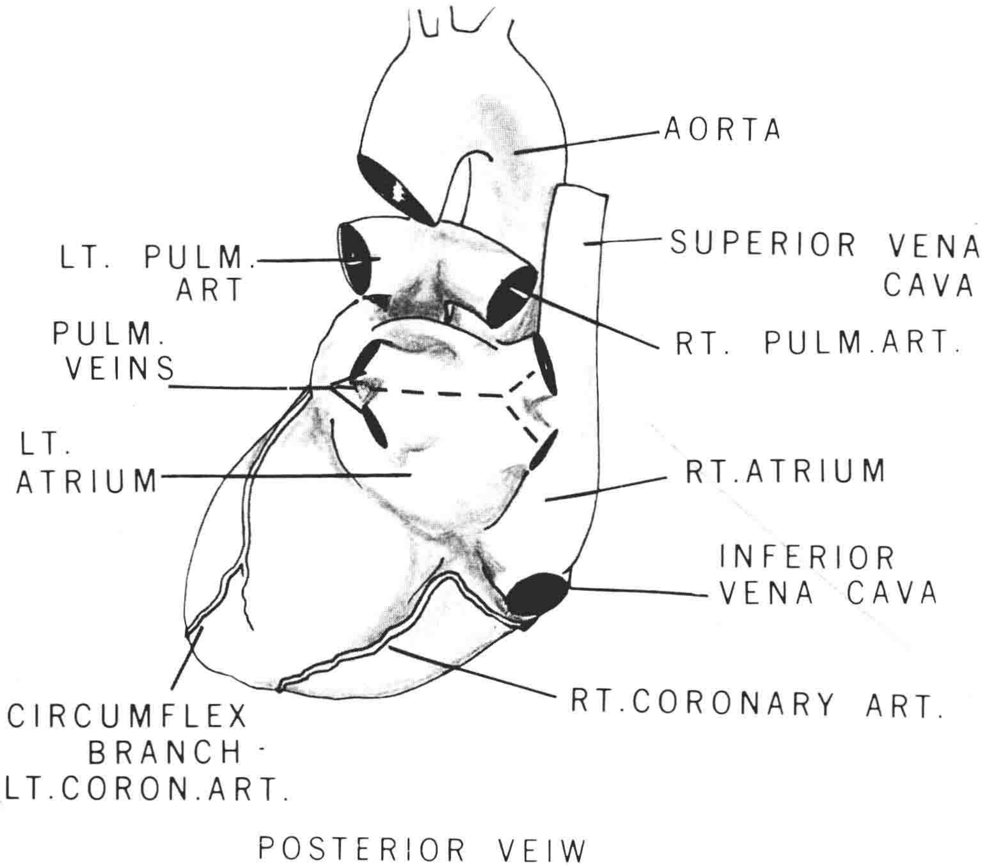

Figure 1.3. Diagrammatic representation of the heart as seen from a posterior view. The left atrium lies posterior to the right atrium and is connected with the pulmonary veins.

on the other hand, have much thicker muscular walls because of their inherent function of pumping blood out of the heart. There are, however, major differences between the right and left ventricles in their size and the amount of muscle mass they possess. The right ventricle is a somewhat larger chamber than the left ventricle but has thinner muscular walls. The left ventricle, on the other hand, has a smaller chamber size but thicker muscular walls. The major difference in the characteristics of the right and left ventricles again resides in their functional needs. The right ventricle receives the desaturated blood returning from the body through the right atrium. This blood in turn is pumped under *low pressure* into the lungs for reoxygenation. The left ventricle receives the oxygenated blood from the lungs, through the left atrium, and must pump this blood out into the aorta to all the tissues of the body. This contraction is done under a *higher pressure*, and more work must be done in order to eject the same amount of blood. Because of these major differences, the size and thickness of the right and left ventricle vary. Despite structural differences, the amount of blood pumped into the lungs is exactly the same as the amount of blood returned from the lungs and pumped out by the left side of the heart. In this manner, a balance between the right and left sides of the heart is maintained and no overloading occurs.

In order to accomplish this complex series of events, there are valves placed between the chambers of the heart and great vessels leading away from the heart to prevent back flow of blood. Thus, the heart basically has two types of heart valves. The atrioventricular valves are located between the atria and the ventricles. These valves permit forward flow of blood into the right and left ventricles during the period of relaxation. At the same time the semilunar valves prevent back flow of blood from the pulmonary artery and aorta. At the time of muscular contraction, the atrioventricular valves form a blood-tight seal to prevent back flow while the ventricles contract and eject the blood out of the heart into the pulmonary artery and aorta.

We will look at the cardiac chambers in more detail and study the different characteristics of these heart valves. In Figure 1.4, we see the right atrium, which occupies the right border of the heart. This cardiac chamber receives desaturated blood returning from the body tissues. The blood is transmitted into the right atrium from the superior and inferior vena cava. The right atrium also receives blood returning from the heart muscle through the great cardiac vein at an opening called the coronary sinus. This blood is then transmitted into the right ventricle at the time of heart relaxation (diastole) through the tricuspid valve. This valve is one of the atrioventricular valves that prevents back flow of blood into the atria at the time of muscular contraction (systole). Located between the right atrium and the right ventricle, the tricuspid valve has three leaflets that are attached to small muscular bundles in the right ventricle by little fibrous strands called chordae tendineae. Looking into the right ventricle, one can see the small papillary muscles with their chordae tendineae attachments connected to the very tips of the tricuspid leaflets. The purpose of the papillary muscles and the chordae tendineae is to prevent the leaflets from bulging back into the right atrium during contraction of the right ventricle. These attachments keep the valve leaflets stationary and prevent blood from leaking across the valve during muscular contraction. The right ventricle is a much more muscular structure than the right atrium. It has many muscular strands crossing over its inner surface (endocardium), which are

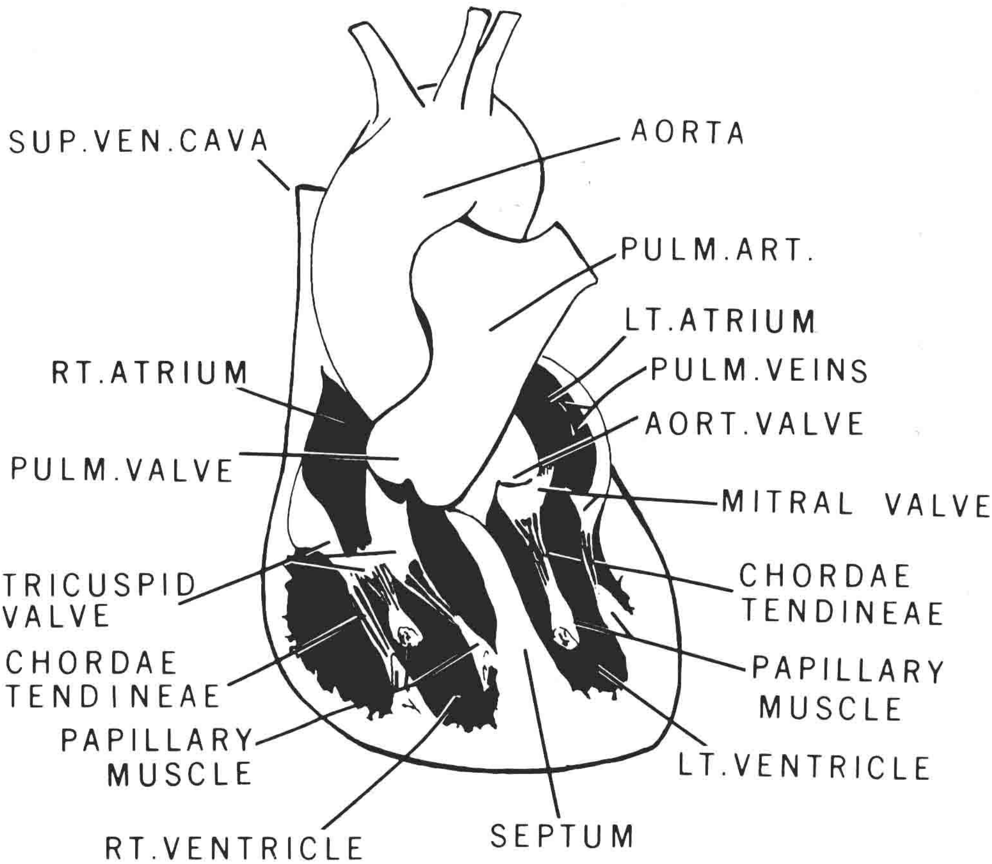

Figure 1.4. Diagrammatic representation of the heart from the frontal view. Note the various relationships of the intracardiac chambers, pulmonary artery and aorta, and the position of the tricuspid valve. Also shown in this figure is the pulmonary valve connecting the right ventricle with the pulmonary artery.

called trabeculae. The muscular wall of the right ventricle is approximately three times as thick as the muscular wall of the right atrium. In the outflow tract of the right ventricle, the pulmonary valve is noted. This is one of the semilunar valves that prevent back flow of blood from the pulmonary artery during the relaxation phase of the heart.

Beyond the pulmonary valve is the main pulmonary artery, which lies anterior to the aorta and subsequently branches into a right and left pulmonary artery to transmit unoxygenated blood to the right and left lungs. The left atrium receives the oxygenated blood from the lungs via four pulmonary veins, two from each lung. This oxygenated blood is then transmitted into the left ventricle during diastole by muscular contraction of the left atrium through the second atrioventricular valve called the mitral valve. The mitral valve has two leaflets, an anterior and a posterior one. As with the tricuspid valve, the mitral valve also has chordae tendineae, which extend from the edge of the leaflets to an anterior and posterior papillary muscle located in the left ventricular cavity. Looking at the left ventricle, one can see that this chamber is slightly smaller than the total size of the right ventricle, and its muscular walls are approximately three times thicker than those of the right ventricle. One can also note the muscular interventricular septum, which separates the right and left ventricles. The aortic valve lies in the outflow tract of the left ventricle, just posterior to the pulmonic valve. The aorta then ascends into the thoracic cavity to form an arch giving off major branches to the head and upper extremities. At the very origin of the aorta just outside of the aortic valve lies a slight dilatation of the aorta called the sinuses of Valsalva. These sinuses are in close relationship with the three cusps of the aortic valve and are called the right, left, and posterior (noncoronary) sinuses.

From the right and left sinuses of Valsalva are the origins of the right and left coronary arteries, respectively. These coronary arteries then course over the outer surface of the heart (epicardium) to supply blood to the myocardial tissue. The right coronary artery, which gains its origin in the right sinus of Valsalva, courses anteriorly in a groove between the right atrium and right ventricle to give off branches to the right atrium and sinus node (in 55% of hearts) and then turns posteriorly and inferiorly to descend in the posterior interventricular groove to supply the blood to this region of the heart. The right coronary artery in 90% of hearts supplies this area of the posterior wall and includes the atrioventricular nodal tissue (Fig. 1.5). The left coronary, on the other hand, originates from the left sinus of Valsalva and courses around the anterior and lateral aspects of the aorta. It immediately divides into two major branches. The first branch, called the left anterior descending, passes downward around the left side of the pulmonary artery in the anterior interventricular groove. This branch gives off smaller branches to the interventricular septum and anterolateral walls of the left ventricle. The other branch of the left coronary artery, called the circumflex branch, runs in the left atrioventricular groove around the left atrium and circles behind the heart. It then supplies branches that course down the posterior wall of the left ventricle as well as branches that supply blood to the posterior and lateral walls of the left ventricle. In 10% of hearts, the circumflex branch is much larger than the posterior branch of the right coronary artery and it is the one that supplies the blood to the atrioventricular nodal tissue.

THE CONDUCTION SYSTEM OF THE HEART

As we have looked into the anatomical aspects of the heart and some of the functional characteristics of specific heart chambers, we have not commented on how the heart actually performs its pumping action. The heart is able to perform this complex pumping action because of a synchronized cycle of contraction. This synchronized contraction pattern is accomplished by electrical stimulation of the muscle. Thus, the heart, just below its endocardial surface, has a complex system of conduction fibers that transmit electrical impulses to the cardiac chambers in order to produce a unified, synchronous muscular contraction (Fig. 1.6).

The location of this initial electrical stimulus, which is the major pacemaker center of the heart, is in the sinus node. This area is in the right atrium at the junction of the superior vena cava. In this region lies a group of specialized myocardial cells that have an inherent rate of electrical discharge. This electrical