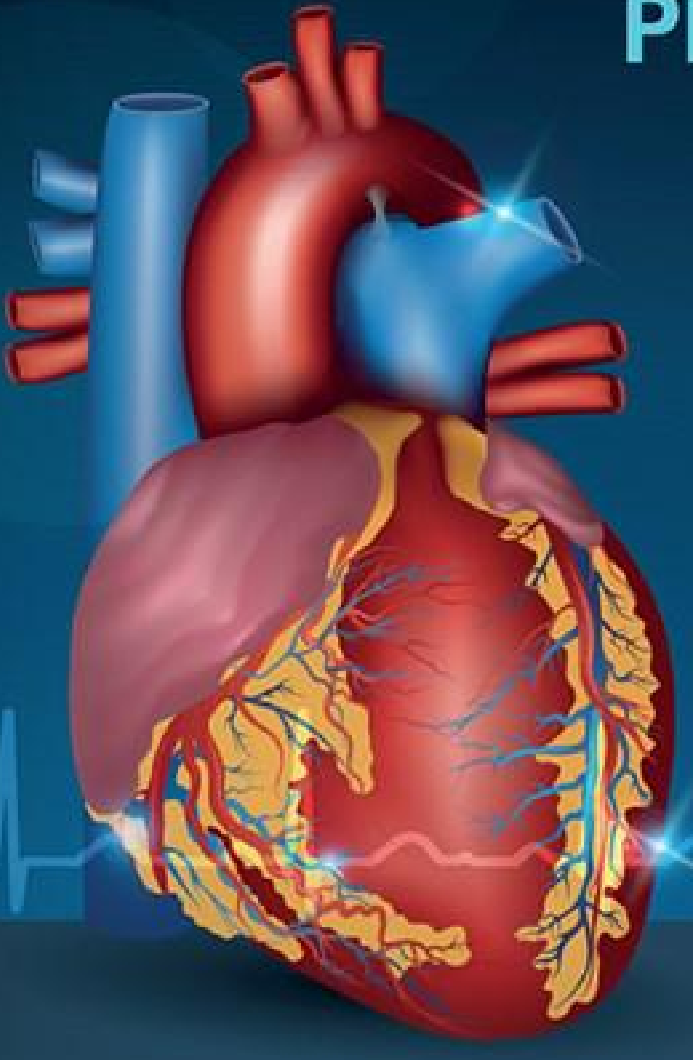
Fourth Edition

EKG

Plain and Simple



Karen M. Ellis

Pearson

FOURTH EDITION

EKG

Plain and Simple

Karen M. **Ellis**, RN

Touro Infirmary, New Orleans

Pearson

330 Hudson Street, NY NY 10013

Library of Congress Cataloging-in-Publication Data
Names: Ellis, Karen M., author.
Title: EKG plain and simple / Karen M. Ellis.
Other titles: Electrocardiography plain and simple
Description: Fourth edition. | Boston : Pearson Education, 2016. |
Includes index.
Identifiers: LCCN 2016030859 | ISBN 9780134525051 | ISBN 0134525051
Subjects: | MESH: Electrocardiography
Classification: LCC RC683.5.E5 | NLM WG 140 | DDC 616.1/207547–dc23
LC record available at https://lccn.loc.gov/2016030859

Publisher: *Julie Levin Alexander*
Publisher's Assistant: *Sarah Henrich*
Director, Portfolio Management: *Marlene Pratt*
Portfolio Manager: *Derril Trakalo*
Content Producer: *Faye Gemmellaro*
Managing Content Producer: *Melissa Bashe*
Editorial Assistant: *Emily Edling*
Development Editor: *Cathy Wein*
Director of Marketing: *David Gesell*
Marketing Manager: *Brittany Hammond*
Manager of Digital Production: *Amy Peltier*
Digital Project Manager: *Lisa Rinaldi*
Full-Service Project Management: *SPi Global*
Composition: *SPi Global*
Production Editor: *Stacy Proteau/SPi Global*
Art Director: *Mary Siener*
Printer/Binder: *Courier Kendallville*
Cover Printer: *Phoenix Color*

Credits: Cover Photo, Part Opener, and Chapter Opener images courtesy of Tefi/Shutterstock. All EKG image strips and uncredited drawings courtesy of Karen M. Ellis. Credits and acknowledgments borrowed from other sources and reproduced, with permission, in this textbook appear on page.

Notice: The author and the publisher of this volume have taken care that the information and technical recommendations contained herein are based on research and expert consultation and are accurate and compatible with the standards generally accepted at the time of publication. Nevertheless, as new information becomes available, changes in clinical and technical practices become necessary. The reader is advised to carefully consult manufacturers' instructions and information material for all supplies and equipment before use and to consult with a health care professional as necessary. This advice is especially important when using new supplies or equipment for clinical purposes. The author and publisher disclaim all responsibility for any liability, loss, injury, or damage incurred as a consequence, directly or indirectly, of the use and application of any of the contents of this volume.

Pearson

10 9 8 7 6 5 4 3 2 1

ISBN-10: 0-13-452505-1
ISBN-13: 978-0-13-452505-1

Contents

Introduction

Welcome to the fourth edition of *EKG Plain and Simple.* This popular text has helped thousands learn how to interpret cardiac rhythms and 12-lead EKGs. The changes in this new edition will make learning even easier. Here's what's new:

"Tweaked" opening scenarios. These improved scenarios emphasize how that chapter's info is clinically important.

Streamlined explanations. The material has been simplified with an emphasis on enhanced comprehension.

Additional tables. This pulls together the info in one place to make retention easier.

More photos and improved art. This makes the book more visually appealing and user-friendly.

As before, we have the following:

Chapter Checkup. This feature pops in at each chapter's halfway mark and asks a few pertinent questions to assess your understanding of the material. It can help you decide if you are ready to move ahead in the chapter or if you need to stop and review first.

Study notes at the end of each chapter. This pulls together all of each chapter's important points in one place and makes studying easier.

Lots of practice strips. Lots of strips in each rhythms chapter and 250 in Chapter 12 make learning rhythm interpretation easier.

Clinical information on rhythms, heart attack symptoms, and treatment. This helps you see the whole person, not just the EKG.

Clinical anecdotes sprinkled throughout. The material makes more sense when it's shown in the context of a real-life situation. And it helps answer the question, "OK, I know what the rhythm/EKG shows; now what do I do with this information?"

Critical Thinking Exercises. Each chapter has exercises that might include case scenarios, diagrams to label, or other exercises that challenge you to put what you learned into practice.

10 scenarios in the final chapter. Chapter 18 is an entire chapter of scenarios that require you to analyze the situation and decide on the rhythm or EKG, the normal treatment, and the expected outcome of that treatment. These scenarios ensure that modern-day clinical issues are represented.

The book starts, as before, with the basics in Part I. First is a little cardiac anatomy and physiology, then EKG waves and complexes, lead morphology, and rhythms. You'll learn what the rhythm is, how to calculate the heart rate, and what the adverse effects and treatments are. There are critical thinking exercises and lots of practice strips to perfect your interpretation skills.

Part II covers 12-lead EKG interpretation. You'll learn what's normal on a 12-lead and what's pathological. Axis, hypertrophy, bundle branch blocks, hemiblocks, myocardial infarction, and pacemakers are just a few topics covered in Part II. Again, there are lots of critical thinking exercises and an entire chapter of 12-leads for practice.

This fourth edition of *EKG Plain and Simple* is written in the same conversational style as the previous editions. Who wants to study some dry, boring textbook?

Karen Ellis

Acknowledgments

To my family, without whom this effort would not have been possible.

Karen

Reviewers

Rick Erikson, NRP, EMS-I, CCP-C, FP-C
Creighton University
Omaha, Nebraska

David Filipp, BS, MS, NREMTP, CCEMTP
Mercy College of Health Sciences
Des Moines, Iowa

Travis Fox, EMT-P
University of Antelope Valley
Palmdale, California

Julie Isaacson, MSN, CCRN
Arkansas State University
Jonesboro, Arkansas

Scott C. Jones, MBA, EMT-P
Victor Valley College
Victorville, California

Dean C. Meenach, AAS, RN, BSN, CEN, CCRN, EMT-P
Mineral Area College
Park Hills, Missouri

Melyssa Munch, CPI, CMA
Star Career Academy
Brick, New Jersey

Auburne Overton, MHA, RPSGT
Mercy College of Health Sciences
Des Moines, Iowa

Krista T. Rodgers, BS, RMA
Miller-Motte Technical College
Charleston, South Carolina

About the Author

Karen Ellis RN, BSN

In her 40-year nursing career, Karen has authored eight articles on various nursing topics for nursing journals as well as three texts on EKG topics for Pearson Education. She has taught EKG interpretation to Allied Health students at the college level and teaches Continuing Education Nursing Inservices on topics such as Basic and 12-lead EKG, Pacemakers, and Congestive Heart Failure. Karen has worked as a nurse in diverse areas such as Psychiatry, Labor and Delivery, and Coronary/Critical Care.

Karen's philosophy of teaching is that learning should be painless, and to that end she uses many clinical anecdotes—and humor—to bring life to potentially boring subject matter.

Infection Control and Patient Privacy Concerns

Healthcare personnel often deal with many different patients every day, so it's important to ensure the safety and privacy of the patients with whom they work.

Infection Control

Say you must do a 12-lead EKG on a patient who has an infection, and then you must go to the next room to do an EKG on a non-infected patient. How do you prevent transmitting that infection from the first patient to you or to the next patient? **Standard Precautions** state that *all patients must be considered potentially infectious* and staff must take steps to prevent contamination of themselves or other patients. What are those steps?

- Handwashing is the single most effective barrier to infection transmission. Wash before and after all patient contact. Let the patient see you washing your hands when you enter and leave their room. It is a reassurance to them.
- **Gloves** should be worn when there is a possibility of contact with body fluids or open wounds. Be attentive to any latex allergy the patient may have, as latex gloves worn by healthcare personnel may prove dangerous or fatal to an allergic patient.
- **Masks/Face shields and gowns** may be required in certain circumstances in which body fluids may splash into the face or onto clothes. Gowns, gloves, and masks/face shields are known as **Personal Protective Equipment (PPE).**
- Following removal of gloves, **alcohol-based disinfectant gel** may be used on your hands (instead of handwashing) if your facility allows it.
- Clean the EKG machine or other devices/machines with a facility-approved disinfectant between patients to prevent any cross-contamination.

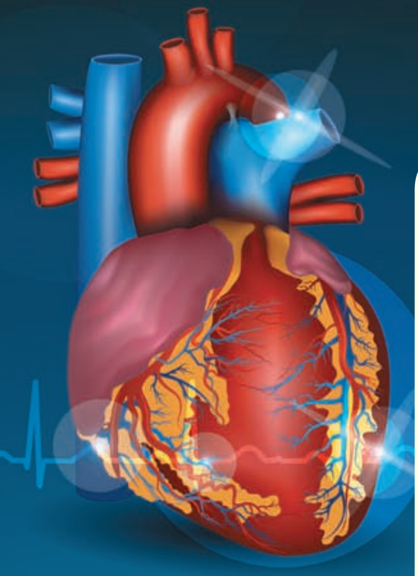
Privacy Concerns

The federal government requires that healthcare personnel guard patients' protected healthcare information (PHI). PHI includes the patient's medical record and other personal health information. HIPAA (Heath Insurance Portability and Accountability Act) privacy laws are very strict and a breach of them can result in fines to the institution whose employee violated the law, and termination of employment for that employee. It is important that you:

- Do not talk about your patients to your family or friends, even though you're sure they don't know the patient.
- Do not disclose PHI to your coworkers *unless they have a work-related need to know this information.* **DO NOT GOSSIP ABOUT YOUR PATIENTS.**
- If you are discussing your patient with a coworker or physician, do not do so in the elevator, in the restroom, in the break room, or in any place where your conversation can be overheard by other people. There have been cases of families suing hospitals after overhearing healthcare personnel discussing their family member's case in the elevator.
- Do not disclose health information to visitors or family of the patient.
- Do not make copies of the patient's records unless it is for required hospital or institutional use.
- Do not disclose PHI to another facility unless the patient or representative has given written permission.
- If there is any question whether or not to disclose protected health information, **do not disclose.**

PART ONE

The Basics



Cardiac Anatomy and Physiology

1

CHAPTER 1 OBJECTIVES

Upon completion of this chapter, the student will be able to

- State the location of the heart and its normal size.
- Name the walls and layers of the heart.
- Name all the structures of the heart.
- Track the flow of blood through the heart.
- State the oxygen saturation of the heart's chambers.
- Describe the function and location of the heart valves.
- Describe the relationship of the valves to heart sounds.
- List the great vessels and the chamber into which they empty or from which they arise.
- State what occurs in each phase of the cardiac cycle.
- Name and describe the function of the coronary arteries.
- Differentiate between the two kinds of cardiac cells.
- Describe the sympathetic and parasympathetic nervous systems.
- Describe the *fight-or-flight* and *rest-and-digest* responses.

What It's All About

Mr. Huckabee was scheduled for heart surgery in the morning and was very nervous. His surgeon had told him he had a "bad valve" and three blocked coronary arteries, one of which was so bad it could cause a **myocardial infarction** (MI—a heart attack) any minute. All this had been discovered when Mr. Huckabee's heart rhythm became erratic, causing symptoms. The doctor did a cardiac workup on him and found the blockages and the valve problems. So now Mr. Huckabee is in the hospital, nervously awaiting his surgery. When his nurse asked him what exactly he was to have done in surgery the next morning, he replied the surgeon had "talked medicalese" and he hadn't really understood any of it. The nurse took out a model of the heart and pointed out the heart valves and coronary arteries, explaining what they do and how his symptoms were all related to his heart problems. She then explained how the surgery would correct the problems. Mr. Huckabee visibly relaxed afterward, saying he was grateful his nurse took the time to teach him about his heart.

Introduction

The function of the heart, a muscular organ about the size of a man's closed fist, is to pump enough blood to meet the body's metabolic needs. To accomplish this, the heart beats 60 to 100 times per minute and circulates 4 to 8 liters of blood per minute. Thus, each day the average person's heart beats approximately 90,000 times and pumps out about 6,000 liters of blood. With stress, exertion, or certain pathological conditions, these numbers can quadruple.

The heart is located in the **thoracic (chest) cavity**, between the lungs in a cavity called the **mediastinum**, above the diaphragm, behind the **sternum** (breastbone), and in front of the spine. It is entirely surrounded by bony structures for protection. This bony cage also serves as a means to revive the stricken heart, as the external chest compressions of CPR compress the heart between the sternum and spine and squeeze blood out until the heart's function can be restored.

The top of the heart is the **base**, from which the great vessels emerge. The bottom of the heart is the **apex**, the pointy part that rests on the diaphragm. The heart lies at an angle in the chest, with the bottom pointing to the left. See Figure 1–1.

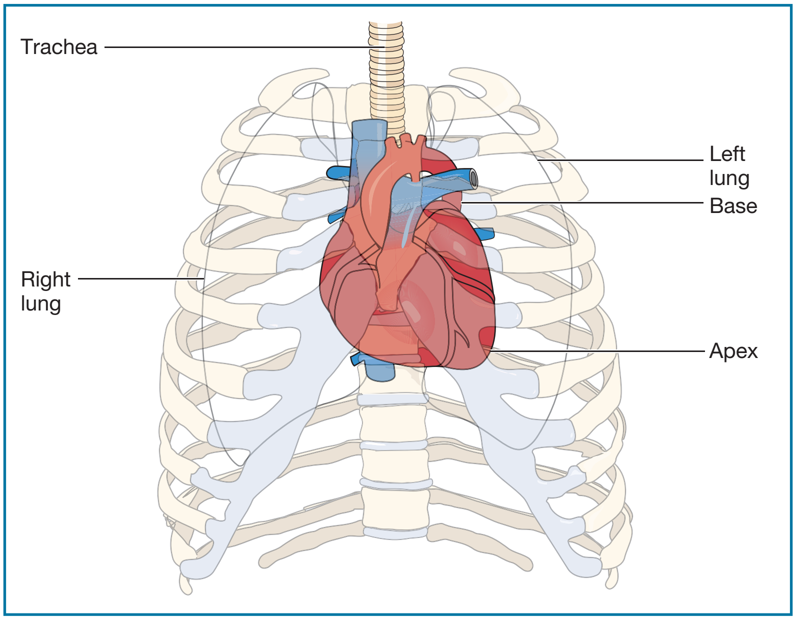


FIGURE 1–1

Heart's location in thoracic cavity.

Layers of the Heart

The heart has three layers:

- **Epicardium** The outermost layer of the heart. The coronary arteries run along this layer.
- **Myocardium** The middle and thickest layer. The myocardium is made of pure muscle and does the work of contracting. It is the part that is damaged during a heart attack.
- **Endocardium** The thin innermost layer that lines the heart's chambers and folds back onto itself to form the heart valves. The endocardium is watertight to prevent leakage of blood into the other layers. The cardiac conduction system is found in this layer.

Surrounding the heart is the **pericardium**, a double-walled sac that encloses the heart. Think of it as the film on a hard-boiled egg. The pericardium serves as support and protection and anchors the heart to the diaphragm and great vessels. A small amount of fluid is found between the layers of the pericardium. This **pericardial fluid** minimizes friction between these layers as they rub against each other with every heartbeat. See Figure 1–2 for an illustration of the heart's anatomy.

Heart Chambers

The heart has four chambers (See Table 1–1):

- **Right atrium** A receiving chamber for deoxygenated blood (blood that's had some oxygen removed by the body's tissues) returning to the heart from the body, the right atrium has an oxygen (O_2) saturation of only 60% to 75%. The blood in this chamber has so little oxygen, its color is dark maroon. Carbon dioxide (CO_2) concentration is high. The right atrium delivers its blood to the right ventricle.
- **Right ventricle** The right ventricle pumps the blood to the lungs for a fresh supply of oxygen. O_2 saturation is 60% to 75%. Again, the blood is dark maroon in color. CO_2 concentration is high.
- **Left atrium** This is a receiving chamber for the blood returning to the heart from the lungs. O_2 saturation is now about 100%. The blood is full of oxygen and is now bright red in color. CO_2 concentration is extremely low, as it was removed by the lungs. The left atrium delivers its blood to the left ventricle.
- **Left ventricle** The left ventricle's job is to pump blood out to the entire body. It is the major pumping chamber of the heart. O_2 saturation is about 100%. Again, the blood is bright red in color. CO_2 concentration is minimal.

TABLE 1–1 Heart Chambers

Chamber	O_2 Saturation	Receives Blood From	Delivers Blood To
Right atrium	60–75%	Body	Right ventricle
Right ventricle	60–75%	Right atrium	Lungs
Left atrium	~100%	Lungs	Left ventricle
Left ventricle	~100%	Left atrium	Body (systemic circulation)

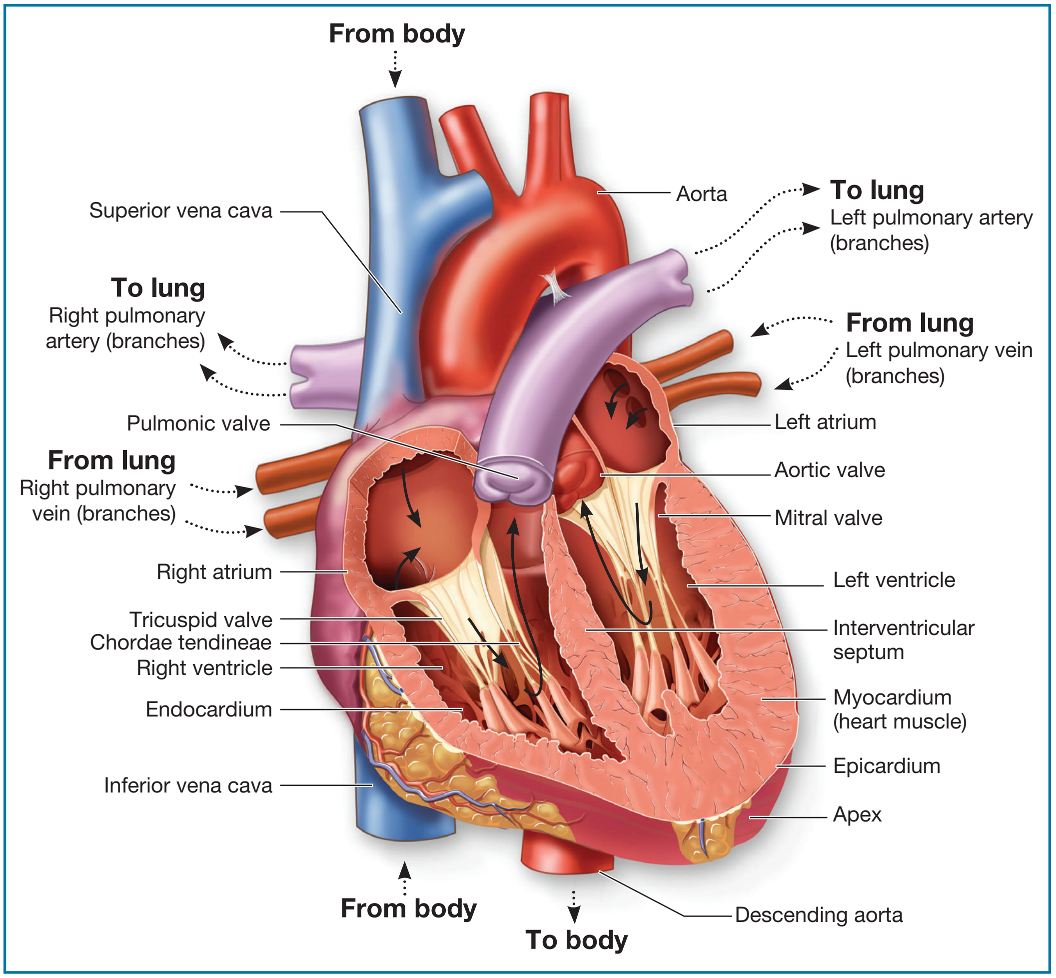


FIGURE 1–2

The heart: Its layers, chambers, and blood flow.

The atria's job is to deliver blood to the ventricles that lie directly below them. Because this is a short trip and minimal contraction is needed to transport this blood to the ventricles, the atria are thin-walled, low-pressure chambers.

The ventricles, on the other hand, are higher-pressure chambers because they must contract more forcefully to deliver their blood into the pulmonary system and the systemic circulation. Because the right ventricle must pump its blood only to the nearby lungs, and pulmonary pressures are normally low, the right ventricle's pressure is relatively low and its muscle bulk is relatively thin. The left ventricle generates the highest pressures, as it not only must pump the blood the farthest (throughout the entire body), it also must pump against great resistance—the blood pressure. Because of this heavy workload, the left ventricle has three times the muscle bulk of the right ventricle and plays the prominent role in the heart's function.

The heart is divided into right and left sides by the **septum**, a muscular band of tissue. The septum separating the atria is called the **interatrial septum**. The septum separating the ventricles is called the **interventricular septum**.

Heart Valves

The heart has four valves to prevent backflow of blood. Two are semilunar valves and two are atrioventricular (AV) valves.

Semilunar valves separate a ventricle from an artery and have three half-moon-shaped cusps. The term *semilunar* means half moon. There are two *semilunar* valves.

- **Pulmonic valve** This valve is located between the right ventricle and the pulmonary artery.
- **Aortic valve** The aortic valve is located between the left ventricle and the aorta.

AV valves are located between an atrium and a ventricle. They are supported by **chordae tendineae** (tendonous cords), which are attached to **papillary muscles** (muscles that outpouch from the ventricular wall) and anchor the valve cusps to keep the closed AV valves from flopping backward and allowing backflow of blood. There are two AV valves.

- **Tricuspid** This valve, located between the right atrium and ventricle, has three cusps.
- **Mitral** The mitral valve, also called the *bicuspid valve,* is located between the left atrium and ventricle. It has two cusps.

Valves open and close based on changes in pressure. *And they open only in the direction of blood flow.* Blood flows down from atrium to ventricle, and up from ventricle to aorta and pulmonary artery. For example, the tricuspid and mitral valves are located between the right atrium and ventricle and the left atrium and ventricle, respectively. Because blood flows down from atrium to ventricle, these valves open only one way—down. Thus, when the atria's pressure is higher than the ventricles' pressure, the tricuspid and mitral valves open to allow blood to flow into the waiting ventricles. The aortic and pulmonic valves open upward only when the pressure in the ventricles exceeds that in the waiting aorta and pulmonary artery. Blood then flows up into those arteries. See Table 1–2.

Valve closure is responsible for the sounds made by the beating heart. The normal lub-dub of the heart is made not by blood flowing through the heart, but by the closing of the heart's valves. S1, the first heart sound, reflects closure of the mitral and tricuspid valves. S2, the second heart sound, reflects closure of the aortic and pulmonic valves. Between S1 and S2, the heart beats and expels its blood (called **systole**). Between S2 and the next S1, the heart rests and fills with blood (called **diastole**). Each heartbeat has an S1 and S2. Note the valves on Figure 1–2.

Great Vessels

Attached to the heart at its base are the five great vessels.

- **Superior vena cava (SVC)** The SVC is the large vein that returns deoxygenated blood to the right atrium from the head, neck, and upper chest and arms.
- **Inferior vena cava (IVC)** The IVC is the large vein that returns deoxygenated blood to the right atrium from the lower chest, abdomen, and legs.
- **Pulmonary artery** This is the large artery that takes deoxygenated blood from the right ventricle to the lungs to load up on oxygen and unload carbon dioxide. It is the *only* artery that carries deoxygenated blood.
- **Pulmonary veins** These are four large veins that return the oxygenated blood from the lungs to the left atrium. They are the *only* veins that carry oxygenated blood.
- **Aorta** The aorta is the largest artery in the body. It takes oxygenated blood from the left ventricle to the systemic circulation to feed all the organs of the body.

Note the great vessels on Figure 1–2. See Table 1–3.

TABLE 1–2 Heart Valves

Valve	Location	Direction of Valve Opening
Pulmonic	Between right ventricle and pulmonary artery	Opens upward into pulmonary artery
Aortic	Between left ventricle and aorta	Opens upward into aorta
Tricuspid	Between right atrium and right ventricle	Opens downward into right ventricle
Mitral	Between left atrium and left ventricle	Opens downward into left ventricle

TABLE 1–3 Great Vessels

Vessel	Kind of Vessel	Oxygen Status of Transported Blood	Transports Blood from:	Transports Blood to:
Superior vena cava (SVC)	Vein	Deoxygenated	Head, neck, upper chest, arms	Right atrium
Inferior vena cava (IVC)	Vein	Deoxygenated	Lower chest, abdomen, legs	Right atrium
Pulmonary artery	Artery	Deoxygenated	Right ventricle	Lungs
Pulmonic veins	Veins	Oxygenated	Lungs	Left atrium
Aorta	Artery	Oxygenated	Left ventricle	Body

Blood Flow Through the Heart

Now let's track a single blood cell as it travels through the heart:

Superior or inferior vena cava → right atrium → tricuspid valve → right ventricle → pulmonic valve →→ pulmonary artery →→ lungs →→ pulmonary veins →→ left atrium →→ mitral valve →→ left ventricle →→ aortic valve →→ aorta →→ body (systemic circulation)

- The blood cell enters the heart via either the **superior** or **inferior vena cava**.
- It then enters the **right atrium**.
- Next it travels through the **tricuspid valve** into the **right ventricle**.
- Then it passes through the **pulmonic valve** into the **pulmonary artery**, then into the **lungs** for oxygen/carbon dioxide exchange.
- It is then sent through the **pulmonary veins** to the **left atrium**.
- Then it travels through the **mitral valve** into the **left ventricle**.
- It passes through the **aortic valve** into the **aorta** and out to the **body (systemic circulation)**.

chapter CHECKUP

We're about halfway through this chapter. To evaluate your understanding of the material thus far, answer the following questions. If you have trouble with them, review the material again before continuing.

1. Name the heart layers, chambers, valves, and great vessels. Describe the function of each.
2. Track the flow of blood through the heart.

Blood flow through the heart is accomplished by way of the cardiac cycle. Let's look at that now.

Quick Tip

Rapid-filling phase = atria pouring blood into ventricles

Diastasis = slowing blood flow

Atrial kick = atria contracting to squeeze remainder of blood into ventricles

The Cardiac Cycle

The **cardiac cycle** refers to the mechanical events that occur to pump blood. There are two phases to the cardiac cycle—diastole and systole. During diastole, the ventricles relax and fill. During systole, the ventricles contract and expel their blood. Each of these phases has several phases of its own. See Figures 1–3 and 1–4 and Tables 1–4 and 1–5.

Diastole

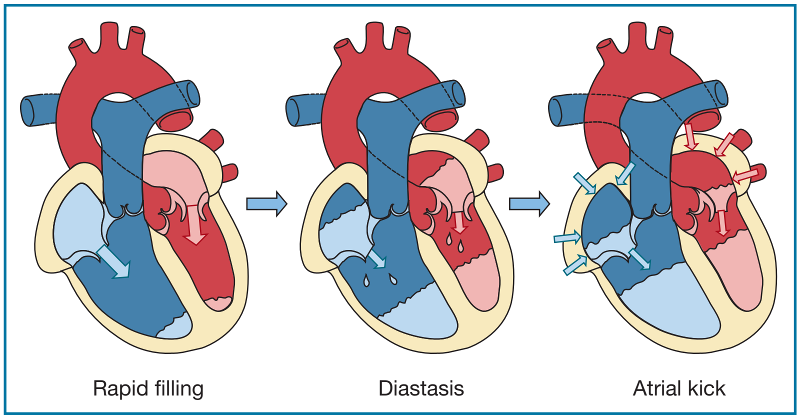


FIGURE 1–3

Phases of diastole.

- **Rapid-filling phase** This is the first phase of diastole. The atria, having received blood from the superior and inferior vena cava, are full of blood and therefore have high pressure. The ventricles, having just expelled their blood into the pulmonary artery and the aorta, are essentially empty and have lower pressure. This difference in pressure causes the AV valves to pop open and the atrial blood to flow down to the ventricles. To envision this, imagine two water balloons connected at their necks, one above the other. The top balloon is full, representing the atrium; the empty bottom one is the ventricle. Imagine a pressure-sensitive valve separating the two balloons. Once this valve is popped open by the pressure difference, the water in the top full balloon will pour down into the empty bottom one. That's the rapid filling phase. The ventricles are filling with blood from the atria.
- **Diastasis** Diastasis is the second phase of diastole. The pressure in the atria and ventricles starts to equalize as the ventricles fill and the atria empty, so blood flow slows. The fluid levels of the two balloons are equalizing, causing an equalization in pressure, so the flow from top to bottom slows until the top is almost empty and the bottom is almost full.
- **Atrial kick** Atrial kick is the last phase of diastole. The atria are essentially empty, but there is still a little blood to deliver to the ventricle. Because the top balloon is almost empty of water, what must be done to get the last little bit of water out of it? Squeeze. The atria contract, squeezing in on themselves and propelling the remainder of the blood into the ventricles. The pressure in the ventricles at the end of this phase is high, as the ventricles are now full. Atrial pressure is low, as the atria are essentially empty. The AV valve leaflets, which have been hanging down in the ventricle in their open position, are pushed upward by the higher ventricular volume and its sharply rising pressure until they slam shut, ending diastole. S1 is heard at this time. Atrial kick provides 15% to 30% of ventricular filling and is an important phase.

Some heart rhythm abnormalities cause a loss of the atrial kick. This causes a decrease in **cardiac output** (amount of blood pumped by the heart every minute).

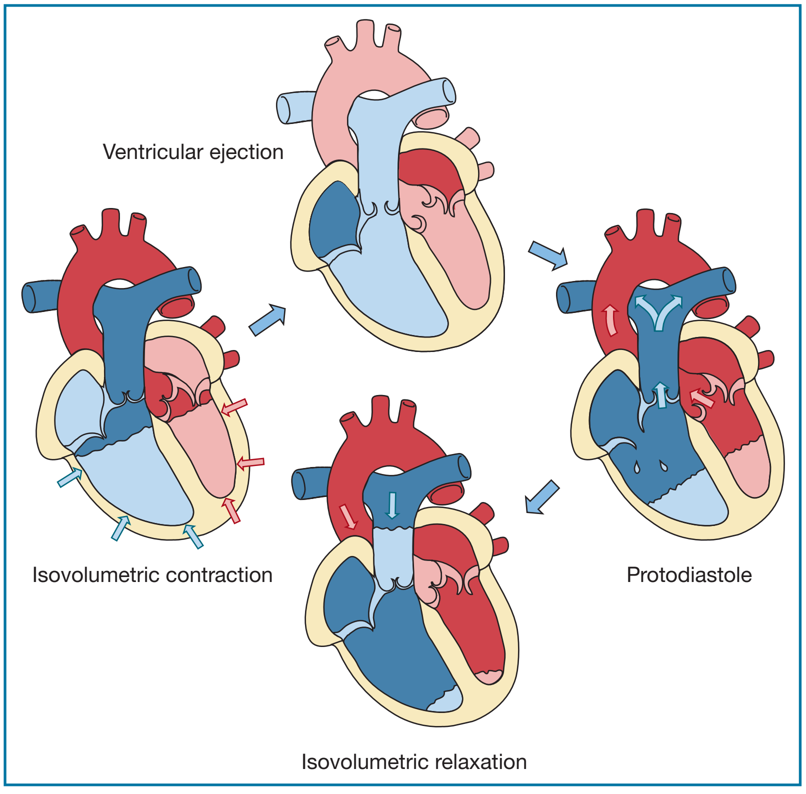


FIGURE 1–4

Phases of systole.

Systole

- **Isovolumetric contraction** This is the first phase of systole. All valves are closed. The ventricles are full, but the pressure in them is not yet high enough to exceed the blood pressure and pop the semilunar valves open. Because the ventricles cannot increase their pressure by adding more volume (they are as full as they are going to get with those valves closed),

TABLE 1–4 Diastole

Phase	Atrial pressure at start of phase	Ventricular pressure at start of phase	Valve action during phase	Blood flow
Rapid filling	High (atria full of blood)	Low (ventricles essentially empty)	AV valves pop open	Strong flow of blood down from atria to ventricles
Diastasis	Equalizing	Equalizing	AV valves remain open	Flow from atria to ventricles slows, as pressure equalizes between atria and ventricles.
Atrial kick	Low (atria almost empty)	High (ventricles almost full)	AV valves are open at beginning of phase, then slam shut at end of phase. Diastole is complete once AV valves close.	Atrial contraction (kick) propels remainder of blood into ventricles.

TABLE 1–5 Systole

Phase	Ventricular pressure at start of phase	Aortic/Pulmonary artery pressures at start of phase	Valve action during phase	Blood flow
Isovolumetric contraction	High (ventricles full)	Low (aorta and pulmonary artery essentially empty)	All valves closed	No blood flow. Myocardial contraction occurring, sharply increasing ventricular pressures.
Ventricular ejection	High (ventricles full)	Low (aorta and pulmonary artery essentially empty)	Aortic and pulmonic valves pop open	Blood pours out into aorta and pulmonary artery. Half of blood empties very quickly.
Protodiastole	Equalizing	Equalizing	Aortic and pulmonic valves remain open.	Flow from ventricles into aorta and pulmonary artery slows as pressures equalize between them.
Isovolumetric relaxation	Low (ventricles essentially empty)	High (aorta and pulmonary artery full of blood)	Aortic and pulmonic valves slam shut at end of phase, concluding systole.	Flow out of ventricles stops.

they squeeze down on themselves, forcing their muscular walls inward, putting pressure on the blood inside and causing the ventricular pressure to rise sharply. No blood flow occurs during this phase because all the valves are closed. *This is like squeezing a plastic cola bottle HARD with the cap still on.* This phase results in the greatest consumption of myocardial oxygen.

- **Ventricular ejection** This is the second phase of systole. With the ventricular pressures now high enough, the semilunar valves pop open and blood pours out of the ventricles into the pulmonary artery and the aorta. *The cola bottle has been squeezed so hard, the cap now pops off.* Half the blood empties quickly and the rest a little slower.
- **Protodiastole** Protodiastole is the third phase of systole. Ventricular contraction continues, but blood flow slows as the ventricular pressure drops (because the ventricles are becoming empty) and the aortic and pulmonary arterial pressures rise (because they are filling with blood from the ventricles). Pressures are equalizing between the ventricles and the aorta and pulmonary artery.
- **Isovolumetric relaxation** This is the final phase of systole. Ventricular pressure is low because the blood has essentially been pumped out. The ventricles relax, causing the pressure to drop further. The aorta and pulmonary artery have

Quick Tip

- Isovolumetric contraction = ventricles squeezing but not pumping
- Ventricular ejection = pumping vigorously
- Protodiastole = pumping less
- Isovolumetric relaxation = relaxing, valves closing to end systole

higher pressures now, as they are full of blood. Because there is no longer any forward pressure from the ventricles to propel this blood further into the aorta and pulmonary artery, some of the blood in these arteries starts to flow back toward the aortic and pulmonic valves. This back pressure causes the valve leaflets, which had been pushed up into the aorta and pulmonary arteries in their open position, to slam shut, ending systole. S2 is heard now.

Quick Tip

When the ventricles are expelling their blood, the atria are filling with blood. And when the atria are expelling their blood, the ventricles are filling. The chambers are either filling or expelling continuously.

Blood Flow Through the Systemic Circulation

We've tracked the flow of blood through the heart. Now let's track its course as it heads throughout the systemic circulation:

Aorta →→ arteries →→ arterioles →→ capillary bed →→ venules →→ veins →→ vena cava

- Oxygenated blood leaves the aorta and enters the **arteries**, which narrow into **arterioles** and empty into each organ's **capillary bed**, where nutrient and oxygen extraction occurs.
- Then, on the other side of the capillary bed, this now-deoxygenated blood enters narrow **venules**, which widen into **veins**, and then return to the **vena cava** for transport back to the heart. Then the cycle repeats.
  See Figure 1–5.

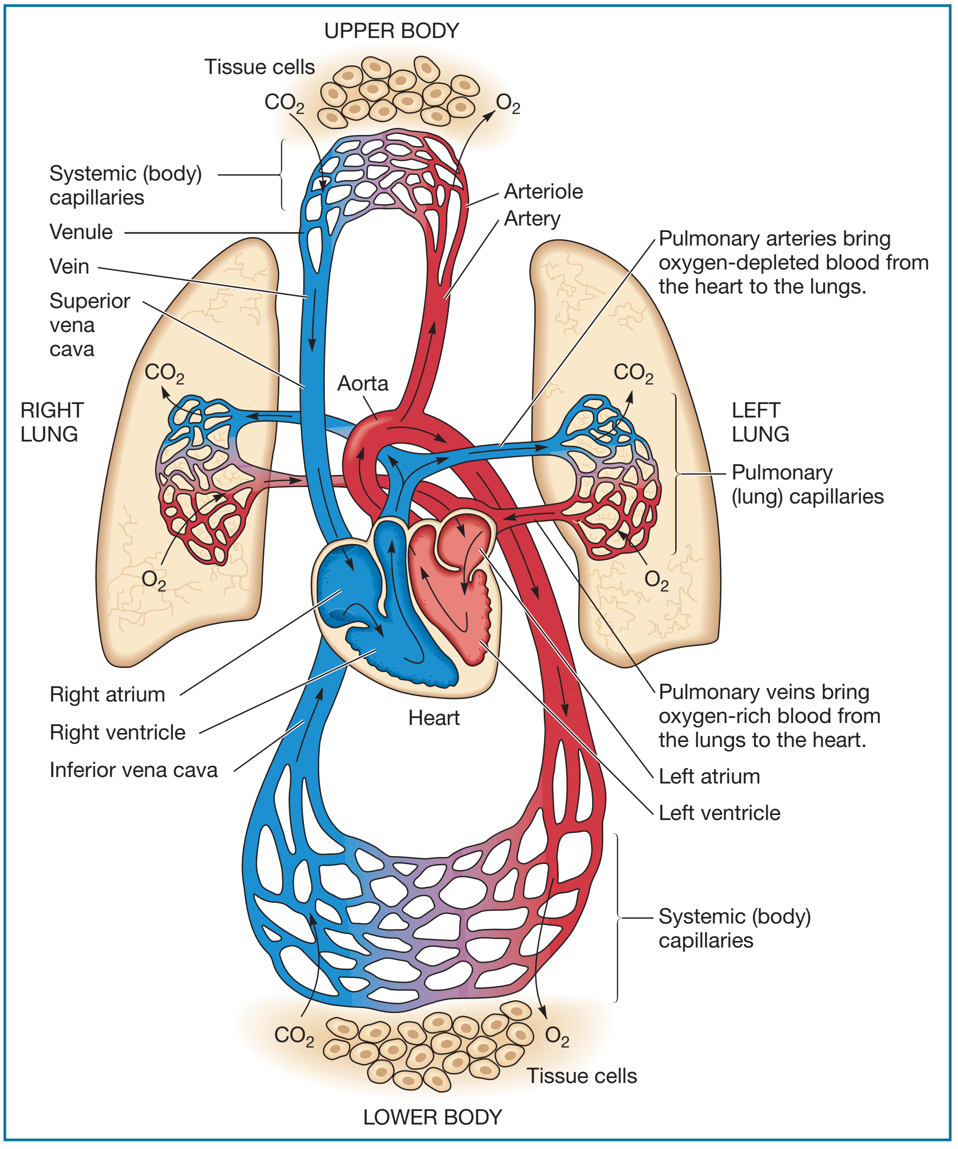


FIGURE 1–5

Systemic circulation.

Coronary Arteries

The heart must not only meet the needs of the body, it has its own needs. With the endocardium being watertight, none of the blood in the chambers can reach the myocardium to nourish it. So the heart has its own circulation—the **coronary arteries**—to do that. Once the myocardium has extracted the nutrients and oxygen from the coronary arteries, the now-deoxygenated blood is returned to the right atrium by the **coronary sinus**, a large **coronary vein**. Let's look at the coronary arteries in more depth.

Coronary arteries arise from the base of the aorta and course along the epicardial surface of the heart, then dive into the myocardium to provide its blood supply. The myocardium, unlike the rest of the body, does not receive its blood supply during systole. Only in diastole is the heart able to feed itself. This is because during systole the heart muscle is contracting and essentially squeezing the coronary arteries shut. During diastole, this contraction stops and the blood can then enter the coronary arteries and feed the myocardium. Let's look at the two main coronary arteries. See Figure 1–6.

- **Left Main Coronary Artery (LMCA)** The left main coronary artery and its two main branches provide blood flow to the anterior and lateral walls of the left ventricle, thus **perfusing** (providing blood flow to) about 60% of the myocardium. Blockage of the LMCA would knock out flow to both its branches and can produce a huge heart attack sometimes referred to as the *widow maker*. Let's look at the LMCA's two main branches.
  - **Left anterior descending (LAD)** The LAD is a branch of the left main coronary artery. The LAD supplies blood to the anterior (front) wall of the left ventricle.
  - **Circumflex** The circumflex, also a branch of the left main coronary artery, feeds the lateral (left side) wall of the left ventricle.
- **Right coronary artery (RCA)** The RCA is the second main coronary artery. It feeds the right ventricle and the inferior (bottom) wall of the left ventricle. In about 70% of people, the RCA gives rise to a branch, the **posterior descending artery (PDA)**, which feeds the posterior wall of the heart. Individuals with the PDA arising from the RCA are referred to as right-dominant, meaning the right

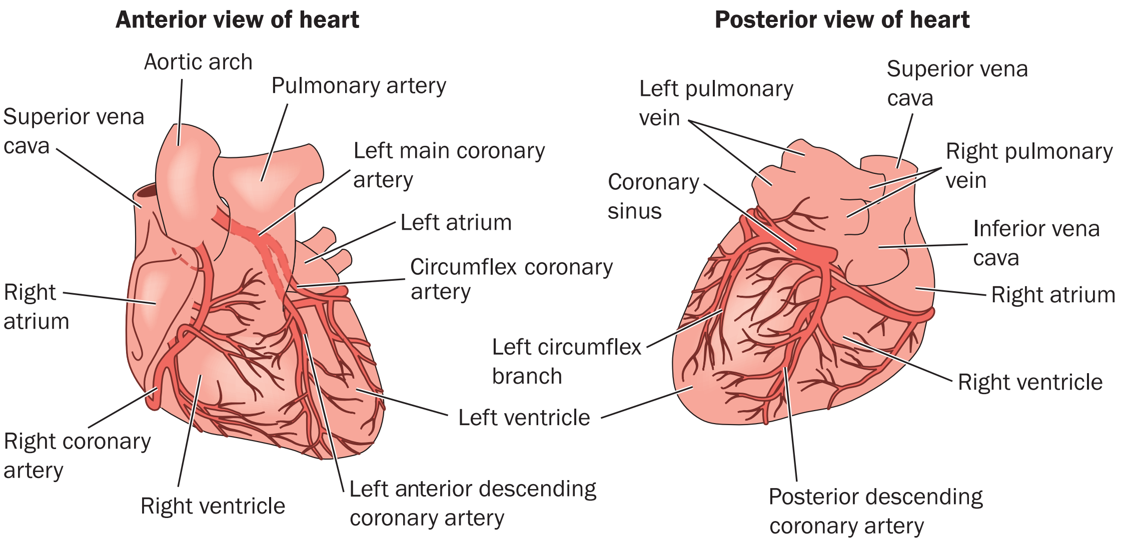


FIGURE 1–6

Coronary arteries (Blamb/Shutterstock).

coronary artery is dominant in perfusing the posterior wall of the heart. In the other 30% of people, the PDA arises from the circumflex coronary artery, which is part of the left coronary artery system. These individuals are referred to as left-dominant. Different coronary artery configurations are common and are not cause for concern, so long as the myocardium is perfused. See Table 1–6 for more info on the areas fed by the coronary arteries.

Heart Cells

The heart has two kinds of cells:

- **Contractile cells** The contractile cells cause the heart muscle to contract, resulting in a heartbeat.
- **Conduction system cells** The conduction system cells create and conduct electrical signals to tell the heart when to beat. Without these electrical signals, the contractile cells would *never* contract.

Nervous Control of the Heart

The heart is influenced by the **autonomic nervous system (ANS)**, which controls involuntary biological functions. The ANS is subdivided into the sympathetic and parasympathetic nervous systems.

The **sympathetic nervous system** is mediated by **norepinephrine**, a chemical released by the adrenal gland. Norepinephrine increases heart rate and blood pressure, causes pupils to dilate, and slows digestion. This is the fight-or-flight response, and it is triggered by stress, exertion, or fear. Imagine you're walking to your car at night and a stranger runs toward you. Your fear triggers the adrenal gland to pour out norepinephrine. Your heart rate and blood pressure shoot up. Your pupils dilate to let in more light so you can see the danger and the escape path better. Digestion slows

TABLE 1–6 Areas Supplied by the Coronary Arteries

Coronary artery	Areas supplied
Left anterior descending	Anterior two-thirds of septum
	Right bundle branch
	Anterior fascicle (branch) of the left bundle branch
	Anterior wall of left ventricle
	Lower segment of AV junction
Circumflex	Sinus node in 45% of people
	Posterior fascicle of the left bundle branch
	Lateral wall of left ventricle
Right coronary artery	Sinus node in 55% of people
	AN node in 90% of people
	Bundle of His
	Posterior fascicle of the left bundle branch
	Posterior third of the septum
	Right atrial and ventricular walls
	Inferior wall of the left ventricle

down as the body shunts blood away from nonvital areas. (Is it essential to be digesting your pizza when your life is at stake? The pizza can wait.) Blood is shunted to vital organs, such as the brain, to help you think more clearly, and to the muscles to help you fight or flee.

The **parasympathetic nervous system** is mediated by **acetylcholine**, a chemical secreted as a result of stimulation of the **vagus nerve**, a nerve that travels from the brain to the heart, stomach, and other areas. It slows the heart rate, decreases blood pressure, and enhances digestion. This is the rest-and-digest response. Parasympathetic stimulation can be caused by any action that closes the **glottis**, the flap over the top of the **trachea** (the windpipe). Breath holding and straining to have a bowel movement are two actions that can cause the heart rate to slow down. It is not uncommon for paramedics to be summoned to the scene of a "person found down" in the bathroom. Straining at stool causes vagal stimulation, which causes the heart rate to slow down. If the heart rate slows enough, **syncope** (fainting) can result. In extreme cases, the heart can stop, requiring resuscitation. Although the heart is influenced by the autonomic nervous system, it can also, in certain extreme circumstances, function for a time without any input from this system. For example, a heart that is removed from a donor in preparation for transplant is no longer in communication with the body, yet it continues to beat on its own for a while. This is possible because of the heart's conduction system cells, which create and conduct electrical impulses to tell the heart to beat.

In a nutshell, the sympathetic nervous system hits the accelerator and the parasympathetic nervous system puts on the brakes.

chapter one notes TO SUM IT ALL UP . . .

- **Heart's function**—Pump enough blood to meet the body's metabolic needs.
- Heart has three layers:
  - *Epicardium*—Outermost layer—where coronary arteries lie.
  - *Myocardium*—Middle muscular layer—does the work of contracting—damaged during a heart attack.
  - *Endocardium*—Innermost layer—watertight—lines the chambers and forms the heart valves. The conduction system is in this layer.
- **Heart has four chambers:**
  - *Right atrium*—Receiving chamber for deoxygenated blood returning to heart from body. Oxygen saturation is 60% to 75%. Blood is dark maroon.
  - *Right ventricle*—Pumps deoxygenated blood to lungs so it can be oxygenated. Oxygen saturation is 60% to 75%. Blood is dark maroon.
  - *Left atrium*—Receiving chamber for oxygenated blood coming from lungs. Oxygen saturation is 100%. Blood is bright red.
  - *Left ventricle*—Major pumping chamber of heart—pumps oxygenated blood to systemic circulation. Oxygen saturation is 100%. Blood is bright red.
- **Interventricular septum**—Band of tissue that separates right and left ventricles.
- **Interatrial septum**—Separates right and left atria.
- **Four heart valves**—Job is to prevent back flow of blood. Valves open in direction of blood flow—AV valves open downward, semilunar valves open upward.
  - *Pulmonic valve*—Semilunar valve between right ventricle and pulmonary artery.
  - *Aortic valve*—Semilunar valve between left ventricle and aorta.
  - *Tricuspid valve*—AV valve between right atrium and right ventricle.
  - *Mitral valve*—AV valve between left atrium and left ventricle.
- **Five great vessels:**
  - *Superior vena cava (SVC)*—Large vein—returns deoxygenated blood from upper body to the heart.
  - *Inferior vena cava (IVC)*—Large vein—returns deoxygenated blood from lower body to the heart.
  - *Pulmonary artery (PA)*—Takes deoxygenated blood from right ventricle to lungs—only artery in the body that carries deoxygenated blood.
  - *Pulmonary veins*—Take oxygenated blood from lungs to left atrium—only veins that carry oxygenated blood.
  - *Aorta (Ao)*—Main artery of the body—carries oxygenated blood to the body.
- **Blood flow through heart:**
  - Superior/inferior vena cava ➜ right atrium ➜ tricuspid valve ➜ right ventricle ➜ pulmonic valve ➜ pulmonary artery ➜ lungs ➜ pulmonary veins ➜ left atrium ➜ mitral valve ➜ left ventricle ➜ aortic valve ➜ aorta ➜ body

- **Cardiac cycle**—Mechanical events that occur to pump blood. Two phases—diastole and systole. **Diastole**—ventricles relax and fill with blood. **Systole**—ventricles contract and expel blood.
- **Diastole**—three phases
  - *Rapid filling*—Atria full of blood, ventricles empty. Pressure differential causes AV valves to pop open—blood rapidly fills ventricles.
  - *Diastasis*—Pressures equalize between atria and ventricles—flow into ventricles slows.
  - *Atrial kick*—Atria contract to squeeze remainder of blood into the ventricles.
- **Systole**—four phases
  - *Isovolumetric contraction*—Ventricles contracting, no blood flow occurring because the aortic and pulmonic valves are still closed. Huge expenditure of myocardial oxygen consumption.
  - *Ventricular ejection*—Valves open—blood pours out of ventricles into pulmonary artery and aorta.
  - *Protodiastole*—Pressures equalize between ventricles and pulmonary artery and aorta—blood flow slows.
  - *Isovolumetric relaxation*—Ventricles relax—pulmonic and aortic valves close.
- **Blood flow through the systemic circulation:**
  - Aorta → arteries → arterioles → capillary bed → venules → veins → vena cava
- **Coronary arteries**—Supply blood flow to myocardium. Two major coronary arteries:
  - **Left main coronary artery**—Has two main branches:
    - *Left anterior descending (LAD)*—provides blood flow to anterior wall of left ventricle.
    - *Circumflex*—provides blood flow to lateral wall of left ventricle.
  - **Right coronary artery**—Provides blood flow to right ventricle and inferior wall of left ventricle. Has one major branch in 70% of people—the posterior descending coronary artery. (In the other 30%, the PDA arises from the circumflex coronary artery).
- **Two kinds of heart cells:**
  - *Contractile cells*—Cause the heart to contract, resulting in a heartbeat.
  - *Conduction system cells*—Create and conduct electrical impulses to tell the heart when to beat.
- **Heart influenced by the autonomic nervous system (ANS), which controls involuntary biological functions.** ANS subdivided into sympathetic (SNS) and parasympathetic nervous systems (PNS). Sympathetic nervous system hits the accelerator; parasympathetic puts on the brakes.
  - *SNS*—Mediated by hormone norepinephrine—causes fight-or-flight response—speeds up heart rate, increases blood pressure, dilates pupils, and slows digestion.
  - *PNS*—Mediated by acetylcholine—causes rest-and-digest response. Slows heart rate, lowers blood pressure, enhances digestion.

Practice Quiz

1. The function of the heart is to ____________________

____

2. Name the three layers of the heart. ____________________

____

____

____

3. Name the four chambers of the heart. ____________________

____

____

____

4. Name the four heart valves. ____________________

____

5. The purpose of the heart valves is to ____________________

____

6. Name the five great vessels of the heart. ____________________

____

7. List the phases of diastole. ____________________

____

____

8. List the phases of systole. ____________________

____

____

9. Name the two divisions of the autonomic nervous system. ____________________

____

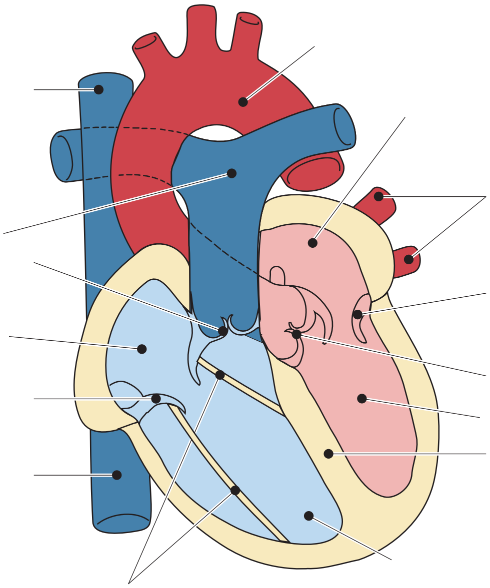
10. The two main coronary arteries are ____________________

____

Putting It All Together—Critical Thinking Exercises

These exercises may consist of diagrams to label, scenarios to analyze, brain-stumping questions to ponder, or other challenging exercises to boost your understanding of the chapter material.

1. Label the heart diagram.



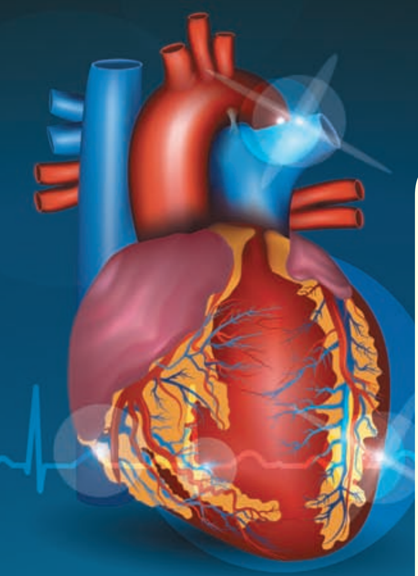
2. Number the following structures 1–14 in the order of blood flow through the heart:

_____ superior and inferior vena cava
_____ pulmonary artery
_____ tricuspid valve
_____ lungs
_____ mitral valve
_____ pulmonary veins
_____ aortic valve
_____ right atrium
_____ pulmonic valve
_____ left atrium
_____ body
_____ right ventricle
_____ aorta
_____ left ventricle

3. What would happen to the tricuspid and mitral valves if their chordae tendineae "snapped" loose?

Electrophysiology

2



CHAPTER 2 OBJECTIVES

Upon completion of this chapter, the student will be able to

- Define the terms *polarized, depolarization,* and *repolarization* and relate them to contraction and relaxation.
- Describe and label the phases of the action potential.
- Define *transmembrane potential*.
- Draw and explain the P wave, QRS complex, T wave, and U wave.
- Explain where the PR and ST segments are located.
- Define the *absolute* and *relative refractory periods* and the implications of each.
- Be able to label, on a rhythm strip, all the waves and complexes.
- Explain the delineations of EKG paper.
- On a rhythm strip, determine if the PR, QRS, and QT intervals are normal or abnormal.
- Name the waves in a variety of QRS complexes.
- Define *pacemaker*.
- List the different pacemakers of the heart and their inherent rates.
- Track the cardiac impulse from the sinus node through the conduction system.
- Define the four characteristics of cardiac cells.
- Describe the difference between *escape* and *usurpation.*
- Define *arrhythmia.*
- Tell what happens:

  When the sinus node fails

  When the sinus node and atria both fail

  When the sinus node, atria, and AV node all fail

What It's All About

Mrs. Mahoney was admitted to the hospital because her physician wanted to watch her closely while he adjusted her heart rhythm medications. Mrs. Mahoney had an extensive cardiac history, including two heart attacks and cardiac arrest. On admission her PR interval was 0.16 seconds, QRS interval was 0.08 secs, QT interval 0.36 secs, heart rate was 88, sinus rhythm—all normal. Mrs. Mahoney's rhythm, intervals, and heart rate were checked every 4 hours per hospital protocol. Sixteen hours after being started on her new medication, her PR and QT intervals had increased. The physician was notified, and he decreased her medication dose. The staff's close assessment of Mrs. Mahoney's intervals allowed the physician to adjust her medication safely.

Introduction

Cardiac cells at rest are electrically negative on the inside compared with the outside. Movement of charged particles (**ions**) of sodium and potassium into and out of the cell causes changes that can be picked up by sensors on the skin and printed out as an EKG.

Depolarization and Repolarization

The negatively charged resting cardiac cell is **polarized**. There are sodium ions primarily outside the cell (extracellular) and potassium ions primarily inside the cell (intracellular). Though both these ions carry a positive electrical charge, the intracellular potassium has a much weaker positive charge than the extracellular sodium. Thus, the inside of the cell is electrically negative compared with the outside. The polarized state is a state of readiness—the cardiac cell is ready for electrical action. When the cardiac cell is stimulated by an electrical impulse, a large amount of sodium rushes into the

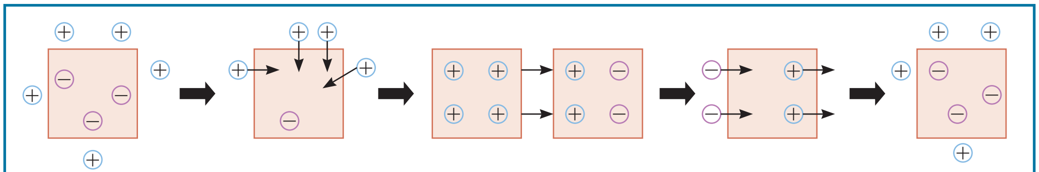


FIGURE 2–1

Depolarization and repolarization.

cell and a small amount of potassium leaks out, causing a discharge of electricity. The cell then becomes positively charged. This is called **depolarization**. An electrical wave then courses from cell to cell like a wave emanating from a pebble tossed into the water. This electrical charge spreads throughout the heart. During cell recovery, sodium and potassium ions are shifted back to their original places by way of the **sodium-potassium pump**, an active transport system that returns the cell to its negative charge. This is called **repolarization**. See Figure 2–1.

Depolarization and repolarization are the myocardium's electrical stimuli. Myocardial contraction and relaxation should be the mechanical response. Depolarization should result in muscle contraction; repolarization should result in muscle relaxation. *Electrical stimulus precedes mechanical response. There can be no heartbeat (a mechanical event) without first having had depolarization (the electrical stimulus).* To illustrate this principle, let's look at a vacuum cleaner. Its mechanical function is to suck up dirt, but it can't do its job without being plugged into an electrical source first. So if your power goes out, your vacuum cleaner won't work, will it? Likewise, if the heart's electrical system "goes out," the heart's pumping will stop. *Electrical stimulus precedes mechanical response.*

What happens if you plug in your vacuum and it still doesn't work? There could be a mechanical malfunction that prevents it from working. Likewise with the heart: The electrical stimulus may be there, but if there is a bad enough mechanical problem with the heart itself, it won't be able to respond to that stimulus by pumping.

The heart's electrical and mechanical systems are two separate systems. They can malfunction separately or together. Electrical malfunctions show up on the EKG. Mechanical malfunctions show up clinically.

Imagine this scenario: A man has a massive heart attack that damages a large portion of his myocardium. His heart's electrical system has not been damaged, so it sends out its impulses as usual. The heart muscle cells, however, have been so damaged that they are unable to respond to those impulses by contracting. Consequently, the EKG shows the electrical system is still working, but the patient's heart is not beating. He has no pulse and is not breathing. The vacuum was plugged in, but it was broken and couldn't do its job. *Electrical stimulus precedes—but does not guarantee—mechanical response.*

The Action Potential

Let's look at what happens to a ventricular muscle cell when it's stimulated. See Figure 2–2. There are five phases to the action potential:

- ***In phase 4.*** The cardiac cell is at rest. It is negatively charged with a resting **transmembrane potential** (the electrical charge at the cell membrane) of

Quick Tip

Depolarization *should* result in muscle contraction. Repolarization *should* result in muscle relaxation.

−90 millivolts. Electrically, nothing is happening. (Note phase 4 is a flat line. *Flat lines indicate electrical silence.*)

- ***In phase 0.*** The cardiac cell is stimulated. Sodium rushes into the cell, and potassium leaks out, resulting in a positive charge within the cell. This is called depolarization. You can see that at the top of phase 0, the cell's charge is above the zero mark, and the cell is thus positively charged. Phase 0 corresponds with the **QRS complex** on the EKG. The QRS complex is a spiked waveform that represents depolarization of the ventricular myocardium.
- ***Phases 1 and 2 are early repolarization.*** Calcium is released in these two phases, resulting in ventricular contraction. Phases 1 and 2 correspond with the ST segment of the EKG. The ST segment is a flat line on the EKG that follows the QRS complex and represents a period of electrical silence. But the heart is not physically at rest—it is contracting. Phase 2 is called the **plateau phase** because the waveform levels off here.
- ***Phase 3 is rapid repolarization.*** Sodium and potassium return to their normal places via the sodium-potassium pump, thus returning the cell to its resting negative charge. Phase 3 corresponds with the **T wave** of the EKG. The T wave is a broad rounded wave that follows the ST segment and represents ventricular repolarization. The cardiac cell then relaxes.

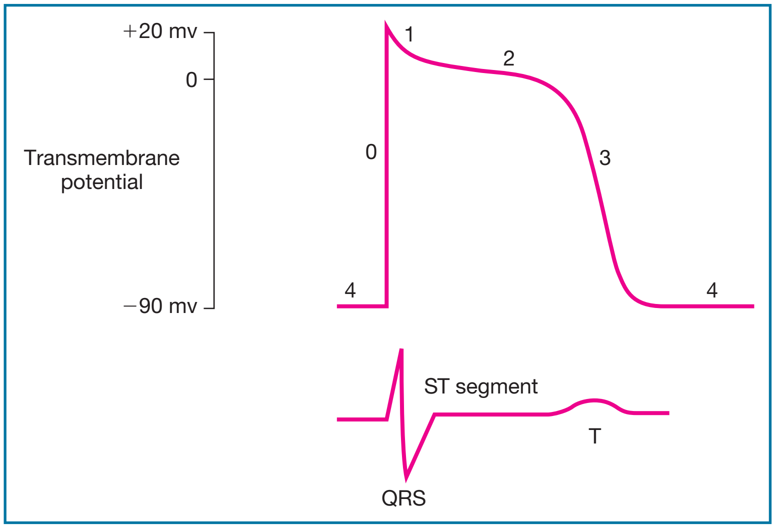


FIGURE 2–2

Action potential.

Refractory Periods

The word **refractory** means "resistant to." Let's look at the periods when the cardiac cell resists responding to an impulse. See Figure 2–3.

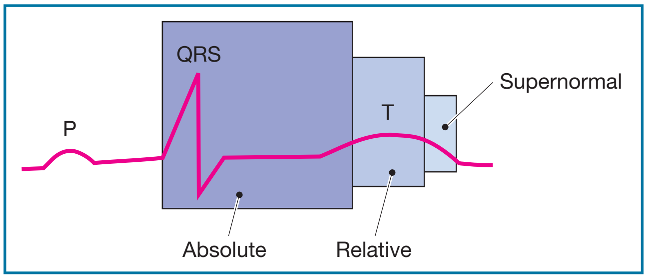


FIGURE 2–3

Refractory periods.

- **Absolute** The cell cannot accept another impulse because it's still dealing with the last one. Absolutely no stimulus, no matter how strong, will result in another depolarization. This is like trying to flush your toilet again immediately after flushing it. No matter how hard you try to flush again right away, the toilet won't flush. It's not ready.
- **Relative** A strong stimulus will result in depolarization. The toilet tank has filled up some, so now it will flush, but not with the same vigor as when the tank is completely full.
- **Supernormal period** Even a weak stimulus will cause depolarization. The cardiac cell is "hyper." Stimulation at this time can result in very fast, dangerous rhythms. The toilet flushes fully again.

EKG Waves and Complexes

Depolarization and repolarization of the atria and ventricles result in waves and complexes on the EKG paper. Let's examine these waveforms. See Figure 2–4.

- **P wave** Represents atrial depolarization. The normal P is small, rounded, and upright, but many things can alter the P wave shape.
- **T_a wave** Represents atrial repolarization—usually not seen, as it occurs at the same time as the QRS complex.

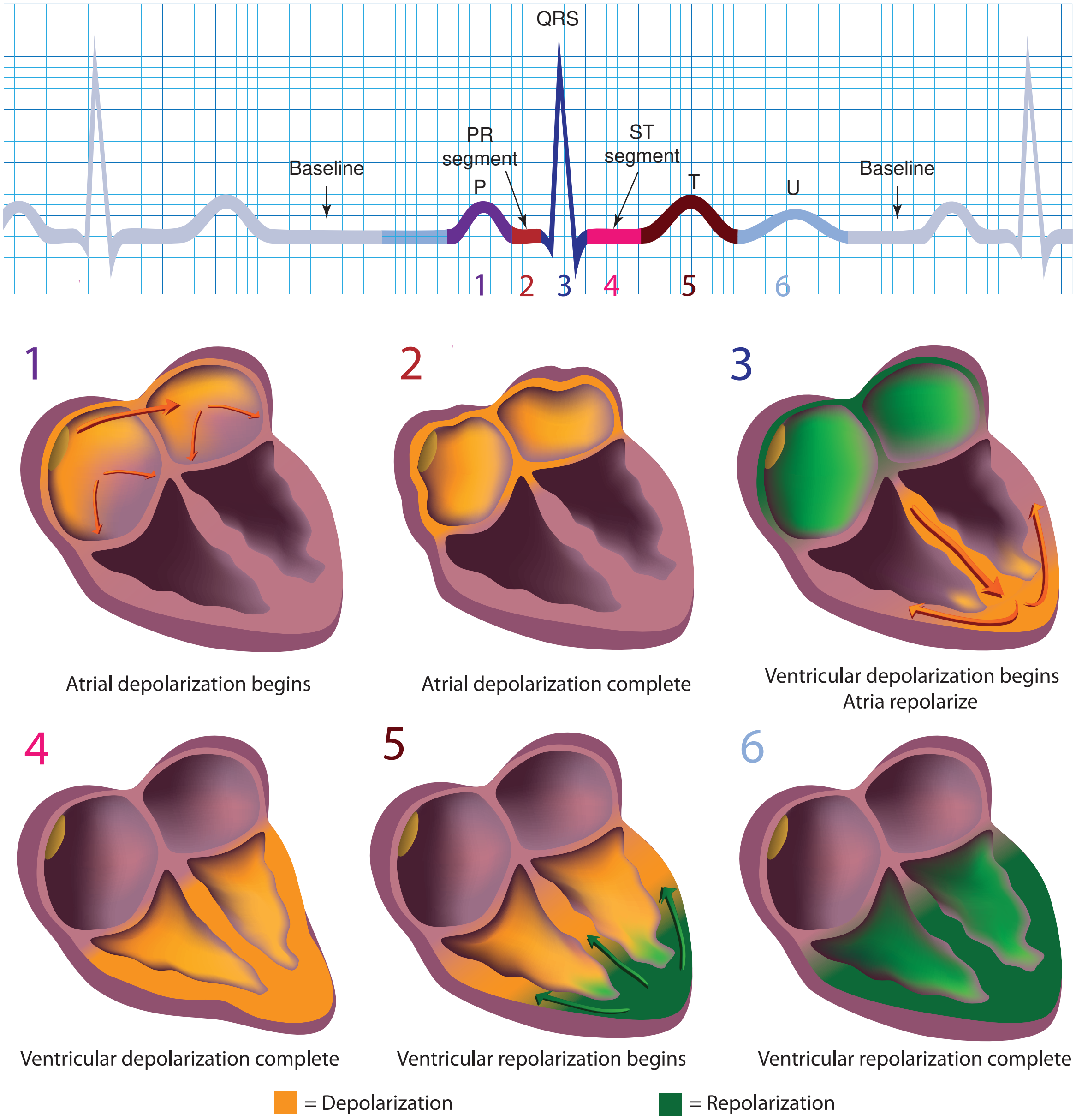


FIGURE 2–4

EKG and electrical activity of the myocardium (Alila Medical Media/Shutterstock).

- **QRS complex** Represents ventricular depolarization. The normal QRS is spiked in appearance, consisting of one or more deflections from the baseline. The QRS complex is the most easily identified structure on the EKG tracing. Its shape can vary.
- **T wave** Represents ventricular repolarization. The normal T wave is broad and rounded. If the QRS is upright, the T wave usually is also. If there is a QRS complex, there *must* be a T wave after it. *Any tissue that depolarizes must repolarize*. Many things can alter the T wave shape.
- **U wave** Represents late ventricular repolarization and is not normally seen. If present, the U wave follows the T wave. It should be shallow and rounded, the same deflection as the T wave (i.e., if the T wave is upright, the U wave should be also).

See Table 2–1 for a summary of the waves and complexes.

TABLE 2–1 Waves and Complexes Summary

Wave	Represents	Normal Shape
P wave	Atrial depolarization	Small, rounded, upright in most leads
T_a wave	Atrial repolarization	Usually not seen as it's inside QRS
QRS complex	Ventricular depolarization	Spiked upward and/or downward deflections
T wave	Ventricular repolarization	Broad, rounded, upright if the QRS is upright
U wave	Late ventricular repolarization	Shallow, broad, rounded, same deflection as T wave

Each P-QRS-T sequence is one heartbeat. The flat lines between the P wave and the QRS and between the QRS and T wave are called the **PR segment** and the **ST segment**, respectively. During these segments, no electrical activity is occurring. (Flat lines indicate electrical silence.) The flat line between the T wave of one beat and the P wave of the next beat is called the **baseline** or **isoelectric line**. The baseline is the line from which the waves and complexes take off.

Atrial contraction occurs during the P wave and the PR segment. Ventricular contraction occurs during the QRS and the ST segment. When the atria depolarize, a P wave is written on the EKG paper. Following this, the atria contract, filling the ventricles with blood. Then the ventricles depolarize, causing a QRS complex on the EKG paper. The ventricles then contract.

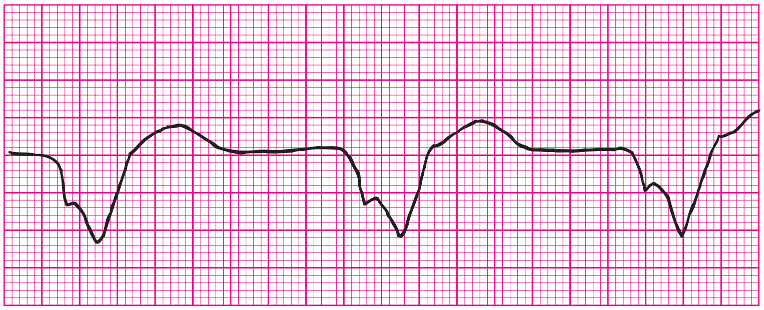
Waves and Complexes Identification Practice

Following are strips on which to practice identifying P waves, QRS complexes, and T waves. You'll recall that P waves are normally upright, but they can also be inverted (upside down) or biphasic (up *and* down). P waves usually precede the QRS complex, so find the QRS and then look for the P wave. Some rhythms have more than one P wave and others have no P at all. Write the letter *P* over each P wave you see.

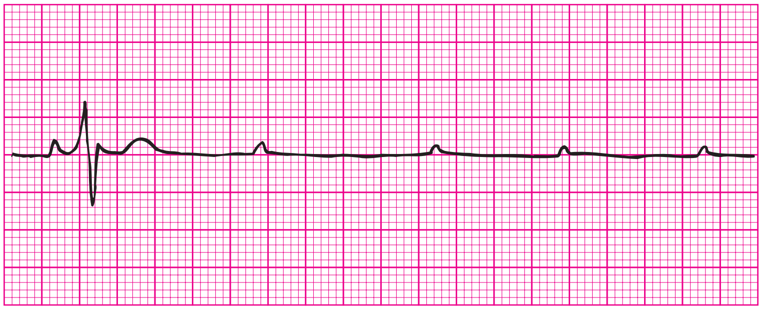
The QRS complex is the most easily identified structure on the strip because of its spiked appearance. Write *QRS* over each QRS complex.

T waves are normally upright but can also be inverted or biphasic. Wherever there is a QRS complex, there must be a T wave. Write a *T* over each T wave.

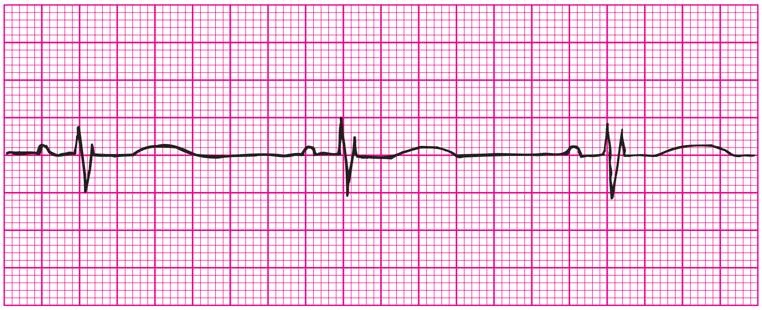
1.



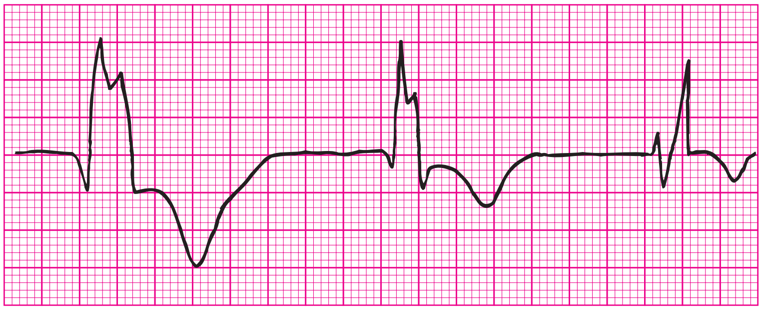
2.



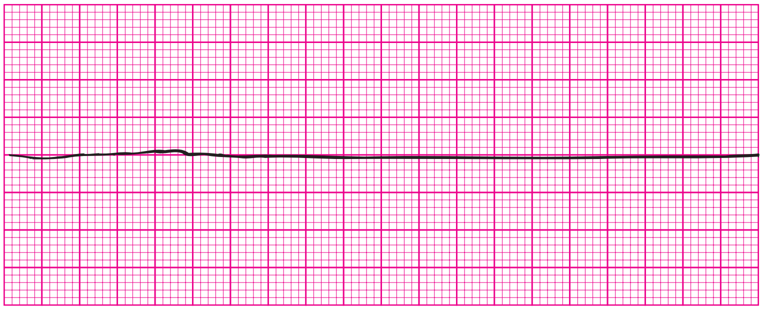
3.



4.



5.



QRS Nomenclature

Now that we know what a QRS complex looks like, let's fine-tune that a bit. The QRS complex is composed of waves that have different names—Q, R, and S—but no matter which waves it is composed of, it's still referred to as the **QRS complex**. Think of it like this: There are many kinds of dogs—collies, boxers, and so on—but they're still dogs. Likewise, the QRS complex can have different names, but it's still a QRS complex. Let's look at the waves that can make up the QRS complex.

Quick Tip

When you name the QRS waves, you're naming the upward and downward spikes that comprise the QRS complex.

- **Q wave** A negative deflection (wave) that occurs before a positive deflection. There can be only one Q wave. If present, it must always be the first wave of the QRS complex.
- **R wave** Any positive deflection. There can be more than one R wave. A second R wave is called **R prime**, written **R'**.

- **S wave** A negative deflection that follows an R wave.
- **QS wave** A negative deflection with no positive deflection at all.

As in the alphabet, Q comes before R and S comes after R. See Figure 2–5. The dotted line indicates the baseline. Any wave in the QRS complex that goes above the baseline is an R wave; any wave going below the baseline is either a Q or an S wave.

See Table 2–2 for a summary of the QRS waves.

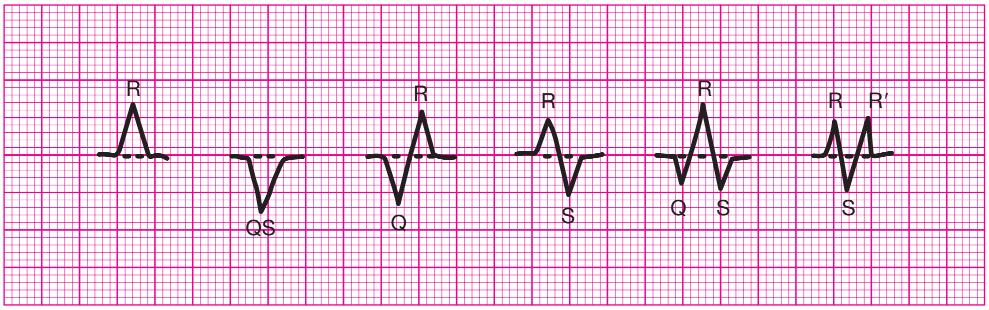


FIGURE 2–5

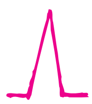
Examples of QRS complexes.

TABLE 2–2 Summary of QRS Waves

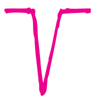
Wave	Deflection	Location	Comments
Q wave	Negative	Precedes R wave	If present, Q wave is *always* first wave of QRS complex
R wave	Positive	Can stand alone or be preceded or followed by Q and/or S	Can have more than one; second R wave is called R prime, written R'
S wave	Negative	Follows R wave	
QS wave	Negative	Stands alone	

QRS Nomenclature Practice

Name the waves in the following QRS complexes:



1. ___________



2. ___________

3. ___________

4. ___________

5. ___________

6. ___________

Now draw the following:

1. RSR'
2. QRS
3. QS
4. QR
5. RS
6. R

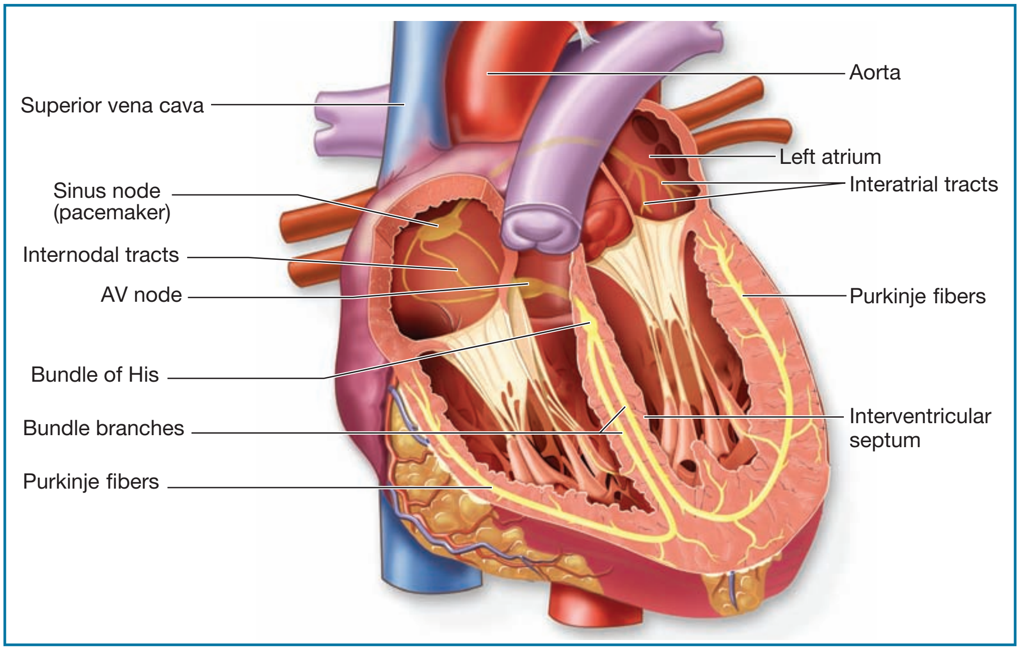


FIGURE 2–6

Cardiac conduction system.

Cardiac Conduction System

The **conduction system** is a pathway of specialized cells whose job is to create and conduct the electrical impulses that tell the heart when to pump. The area of the conduction system that initiates the impulses is called the **pacemaker**. See Figure 2–6.

Conduction Pathway

Let's look at the conduction pathway through the heart

Sinus node →→ interatrial tracts →→ atrium →→ internodal tracts →→ AV node→→ bundle of His →→ bundle branches →→ Purkinje fibers→→ ventricle

- The impulse originates in the **sinus node**, located in the upper right atrium just beneath the opening of the superior vena cava. The sinus node is the heart's normal pacemaker.
- From here it travels through the **interatrial tracts**. These special conductive highways carry the impulses through the atria to the **atrial tissue**. The atria then depolarize, and a P wave is written on the EKG.
- The impulse travels through the **internodal tracts** to the **AV node**, a specialized group of cells located just to the right of the septum in the lower right atrium. The AV node slows impulse transmission a little, allowing the newly depolarized atria to propel their blood into the ventricles.
- Then the impulse travels through the **bundle of His**, located just beneath the AV node, to the left and right **bundle branches**, the main highways to the ventricles.
- Then the impulse is propelled through the **Purkinje fibers**.
- Finally, the impulse arrives at the **ventricle** itself, causing it to depolarize. A QRS complex is written on the EKG paper.

Cardiac Cells

Cardiac cells have several characteristics:

- **Automaticity** The ability to create an impulse without outside stimulation.
- **Conductivity** The ability to pass this impulse along to neighboring cells.

- **Excitability** The ability to respond to this stimulus by depolarizing.
- **Contractility** The ability to contract and do work.

The first three characteristics are electrical. The last is mechanical.

Though the sinus node is the normal pacemaker of the heart, other cardiac cells can become the pacemaker if the sinus node fails. Let's look at that a little more closely. But first let's see how well you understand the material we've covered so far.

chapter CHECKUP

We're about halfway through this chapter. To evaluate your understanding of the material thus far, answer the following questions. If you have trouble with them, review the material again before continuing.

1. Explain *depolarization* and *repolarization*.
2. Name the EKG waves and complexes and state what each represents.
3. Track the electrical current through the conduction system.

Inherent (Escape) Rates of the Pacemaker Cells

- Sinus node: 60 to 100 beats per minute
- AV junction: 40 to 60 beats per minute
- Ventricle: 20 to 40 beats per minute

The sinus node, you will note, has the fastest inherent rate of all the potential pacemaker cells. This means that barring any outside stimuli that speed it up or slow it down, the sinus node will fire regularly at its rate of 60 to 100 beats per minute. The lower pacemakers (AV junction and ventricle) have slower inherent rates, each one having a slower rate than the one above it.

The fastest pacemaker at any given moment is the one in control. The lower pacemakers serve as a backup in case of conduction failure from above, and are inhibited from firing as long as some other pacemaker is faster.

What if the sinus node doesn't create an impulse? The AV junction should then create the impulse and send it down to the ventricle.

What if neither the sinus node nor the AV junction creates the impulse? The ventricle should then create the impulse and conduct it through the ventricular tissue.

Quick Tip

Unlike the sinus node and the ventricle, the AV node itself has no pacemaker cells. The tissue between the atria and the AV node, however—an area called the AV junction—does have pacemaking capabilities. Thus, the term AV node is an anatomical term and AV junction refers to a pacemaking area.

Conduction Variations

Normal conduction of cardiac impulses is dependent on the health of each part of the conduction system. Failure of any part of the system necessitates a variation in conduction. Let's look at several conductive possibilities. In the following figures, the large heart represents the pacemaker in control. See Figure 2–7.

In Figure 2–7, the sinus node fires out its impulse. When the impulse depolarizes the atrium, a P wave is written. The impulse then travels to the AV node, and on to the ventricle. A QRS is written when the ventricle is depolarized.

If the sinus node fails, however, one of the lower pacemakers will escape its restraints and take over at its slower inherent rate, thus becoming the heart's new pacemaker. If the

Quick Tip

Once a lower pacemaker (the AV junction or the ventricle) has received an impulse from above, all it has to do is conduct that impulse down the conduction pathway.

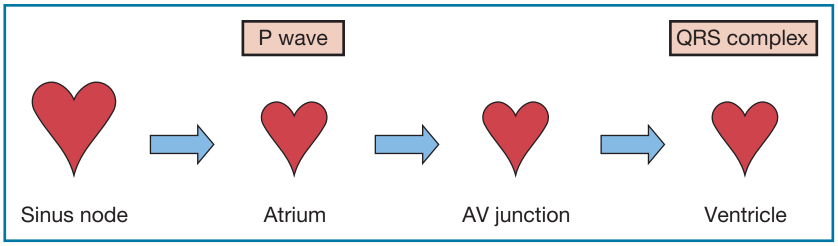


FIGURE 2–7

Normal conduction.

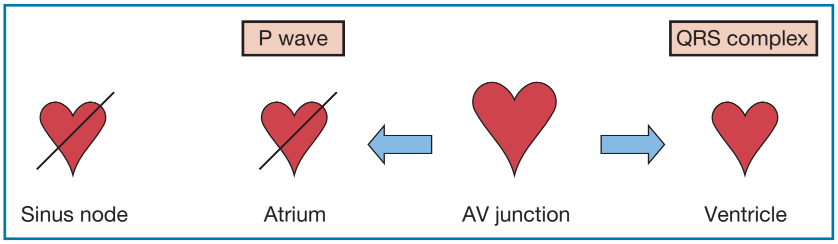


FIGURE 2–8

Sinus fails; AV junction escapes.

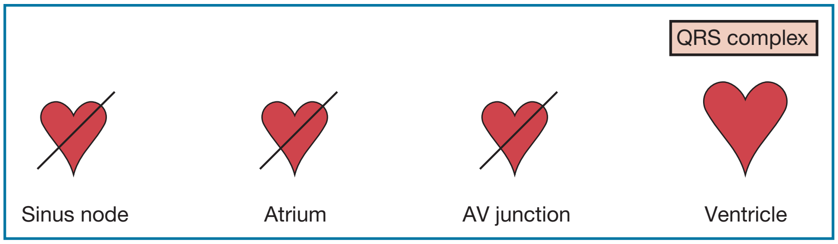


FIGURE 2–9

All higher pacemakers fail; ventricle escapes.

AV junction escapes (takes over as the pacemaker at its slower inherent rate) it will fire at a rate of 40 to 60 beats per minute. If the ventricle takes over, the rate will be 20 to 40 beats per minute. Needless to say, if the ventricle has to kick in as the pacemaker, it is a grave situation, as it means that all the pacemakers above it have failed. Remember—no pacemaker can escape unless it is the fastest at that particular time.

In Figure 2–8, the sinus node has failed. The AV junction is now the fastest escape pacemaker. It creates an impulse and sends it forward toward the ventricle and backward toward the atria, providing the P and the QRS.

In Figure 2–9, both the sinus node and AV junction have failed. The only remaining pacemaker is the ventricle, so it takes over as the pacemaker, providing the QRS. There is no P wave when the ventricle escapes.

What if the sinus node fires its impulse out but the impulse is blocked at some point along the conduction pathway? The first pacemaker below the block should escape and become the new pacemaker.

In Figure 2–10, the sinus node fires out its impulse, which depolarizes the atrium and writes a P wave. The impulse is then blocked between the atrium and the AV node. Because the faster sinus impulse never reaches the AV node, the AV junction assumes the sinus node has failed. So it escapes, creates its own new impulse, and becomes the new pacemaker, sending the impulse down to the ventricle and backward to the atria. (Backward conduction can work even when forward conduction is blocked.)

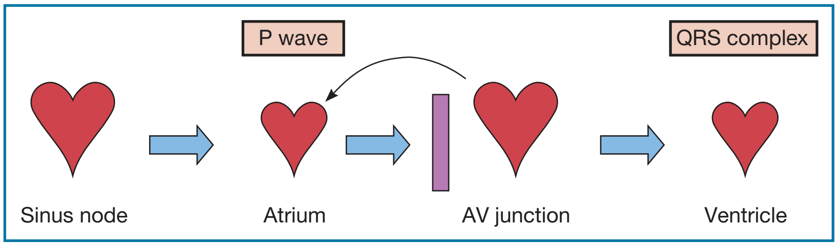


FIGURE 2–10

Block in conduction; AV junction escapes.

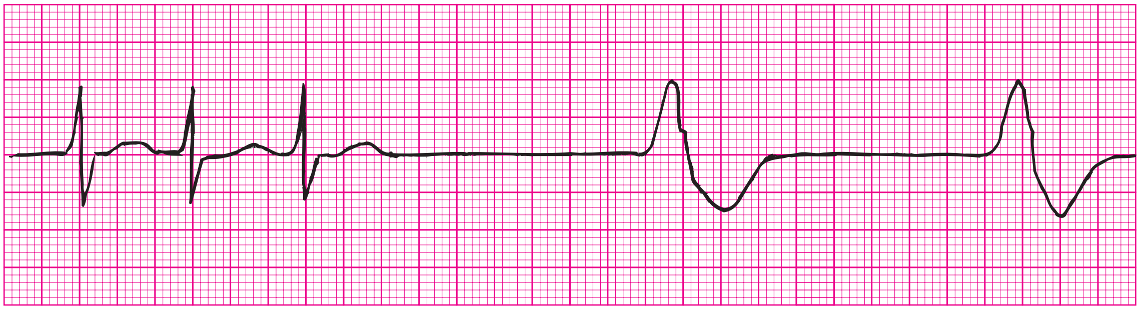


FIGURE 2–11

Escape.

If the impulse were blocked between the AV node and the ventricle, the ventricle should become the new pacemaker.

Each of the pacemakers can fire at rates faster or slower than their inherent rates if there are outside stimuli. We've talked briefly about escape. Let's look at an example of escape compared with usurpation.

Escape occurs when the predominant pacemaker slows dramatically (or fails completely) and a lower pacemaker takes over at its inherent rate, providing a new rhythm that is slower than the previous rhythm. *An escape beat is any beat that comes in after a pause that's longer than the normal heartbeat-to-heartbeat cycle* (**R-R interval**). Escape beats are lifesavers. An **escape rhythm** is a series of escape beats.

In Figure 2–11, the normal pacemaker stops suddenly and there is a long pause, at the end of which is a beat from a lower pacemaker and then a new rhythm with a heart rate slower than before. This is escape.

Usurpation, also called **irritability**, means "to take control away from" and occurs when one of the lower pacemakers becomes irritable and fires in at an accelerated rate, stealing control away from the predominant pacemaker. Usurpation results in a faster rhythm than before, and it starts with a beat that comes in earlier than expected.

In Figure 2–12, the controlling pacemaker is cruising along and suddenly an impulse from a lower pacemaker (the third beat) fires in early, takes control, and is off and running with a new, faster rhythm. This is usurpation.

Proper function of the conduction system results in a **heart rhythm**, a pattern of successive depolarizations, that originates in the sinus node. Abnormalities of the conduction system can produce **arrhythmias**, abnormal heart rhythms. Although these conduction system problems are often related to heart disease, there are also diseases that affect the conduction system outright. Whatever the cause, conduction system abnormalities can prove harmful or fatal if not treated appropriately.

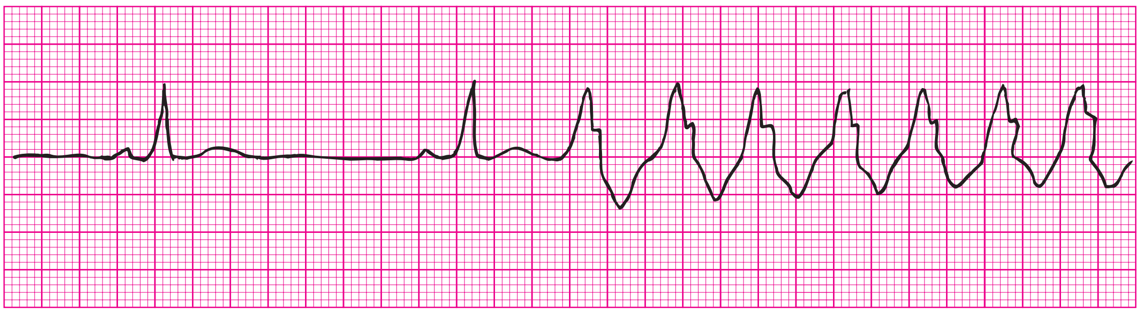


FIGURE 2–12

Usurpation.

TABLE 2–3 EKG Paper Delineations

EKG Feature	Equals
Each small block	0.04 secs (from one small line to the next)
Five small blocks	One big block
One big block	0.20 secs
25 small blocks	1 sec
Five big blocks	1 sec
1,500 small blocks	1 minute
300 big blocks	1 minute
One small block in amplitude	A millimeter

EKG Paper

EKG paper is graph paper divided into small blocks that are 1 millimeter (mm) in height and width. Dark lines are present every fifth block to subdivide the paper vertically and horizontally. Measurements of the EKG waves and complexes are done by counting these blocks. Counting horizontally measures time, or **intervals**. Intervals are measured in seconds. Counting vertically measures **amplitude**, or the height of the complexes. Amplitude is measured in millimeters.

A **12-lead EKG** is a printout of the heart's electrical activity viewed from 12 different angles as seen in 12 different leads. A **lead** is simply an electrocardiographic picture of the heart's electrical activity. A 12-lead EKG is typically done on special paper, using a digital recorder that prints a simultaneous view of three leads at a time in sequence until all 12 leads are recorded.

A **rhythm strip** is a printout of one or two leads at a time and is done to assess the patient's heart rhythm. Rhythm strips are recorded on special paper about 3 to 5 inches wide. A 6- to 12-second strip is usually obtained and interpreted. Rhythm strip paper often has lines at the top of the paper at 1- to 3-second intervals. Let's look at the EKG paper delineations. See Table 2–3. All of these measurements are assuming normal EKG settings.

No matter whether the EKG paper is 12-lead size or rhythm strip size, the delineations will be the same.

Figure 2–13 is an example of EKG paper. **Identifying data**, such as name, date, time, and room number, and **interpretive data**, such as heart rate, are printed at the top

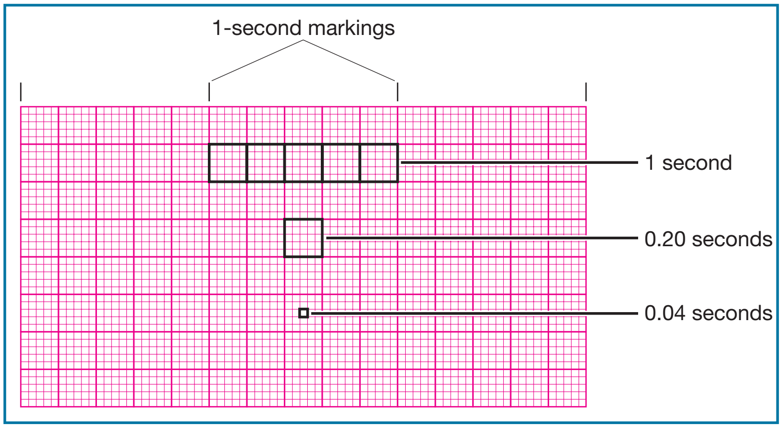


FIGURE 2–13

EKG paper.

(A)

(B)

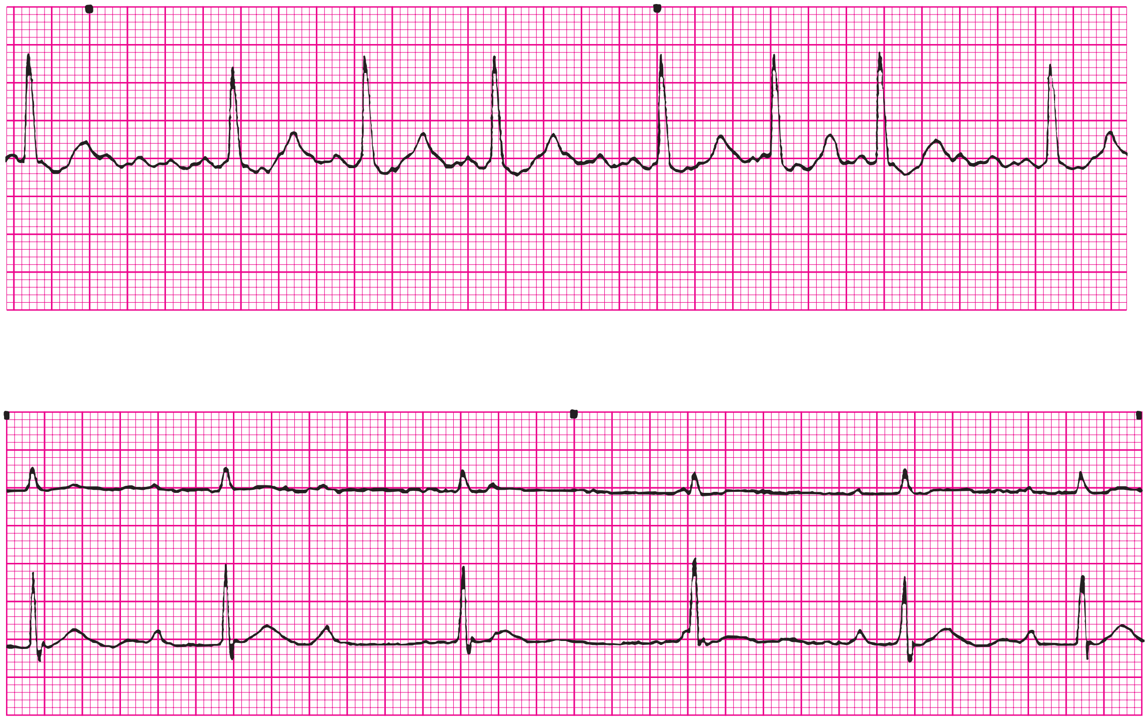


FIGURE 2–14

(A) Single- and (B) double-lead rhythm strips.

of the paper. Figure 2–14 shows single- and double-lead rhythm strips. Note that on the double-lead strip, one lead's waves and complexes show up much more clearly than on the other lead. This is typical.

See Figure 2–15 for a 12-lead EKG. Note the lead markings. Leads are arranged in four columns of three leads. Leads I, II, and III are in the first column, then aVR, aVL, and aVF in the second column, V1 to V3 in the third column, and V4 to V6 in the last column. At the bottom of the paper is a page-wide rhythm strip, usually of either Lead II or V1. Part II of this text covers 12-lead EKGs in more detail.

Intervals

Now let's look at intervals, the measurement of time between the P-QRS-T waves and complexes. The heart's current normally starts in the right atrium and then spreads through both atria and down to the ventricles. Interval measurements enable a determination of the heart's efficiency at transmitting its impulses down the pathway. See Figure 2–16.

- **PR interval** Measures the time it takes for the impulse to get from the atria to the ventricles. Normal PR interval is 0.12 to 0.20 seconds. It's measured from the beginning of the P wave to the beginning of the QRS and includes the P wave and the PR segment. The P wave itself should measure no more than 0.10 seconds wide and 2.5 mm high.
- **QRS interval** Measures the time it takes to depolarize the ventricles. Normal QRS interval is less than 0.12 seconds, usually between 0.06 and 0.10 seconds. It's measured from the beginning of the QRS to the end of the QRS.
- **QT interval** Measures depolarization and repolarization time of the ventricles. The QT interval is measured from the beginning of the QRS to the end of the T wave and includes the QRS complex and the T wave. At normal heart rates of

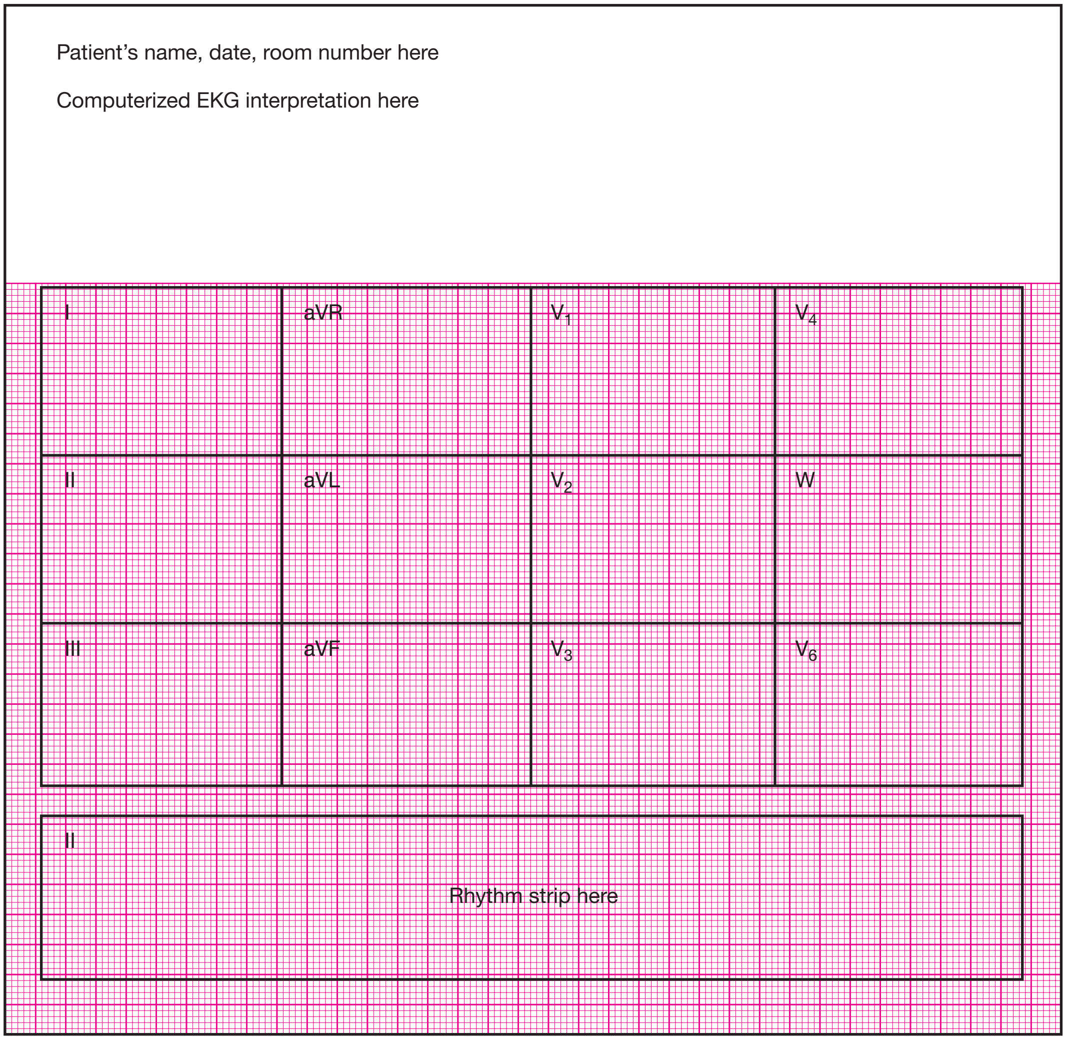


FIGURE 2–15

12-lead EKG.

60 to 100, the QT interval should be less than or equal to one-half the distance between successive QRS complexes (the R-R interval). To quickly determine if the QT is prolonged, draw a line midway between QRS complexes. If the T wave ends at or before this line, the QT is normal. If it ends after the line, it is prolonged and can lead to lethal arrhythmias. QTc is the QT interval corrected for heart rate, and is usually calculated by the EKG machine.

See Table 2–4 for an intervals summary.

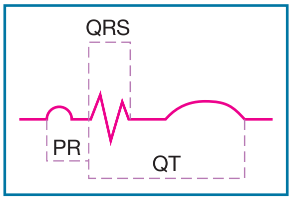


FIGURE 2–16

Intervals.

TABLE 2–4 Intervals Summary

INTERVAL	MEASURES	NORMAL VALUE
PR interval	Time traveling from atrium to ventricle	0.12–0.20 seconds
QRS interval	Ventricular depolarization time	Less than 0.12 seconds (usually between 0.06 and 0.10 seconds)
QT interval	Ventricular depolarization and repolarization time	Varies with heart rate—should be less than half the R-R interval if heart rate 60–100

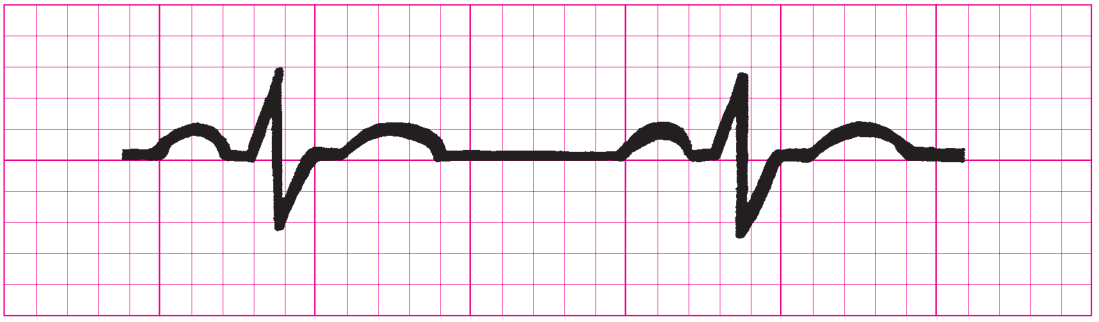
Intervals Practice

Determine the intervals on the enlarged rhythm strips that follow.

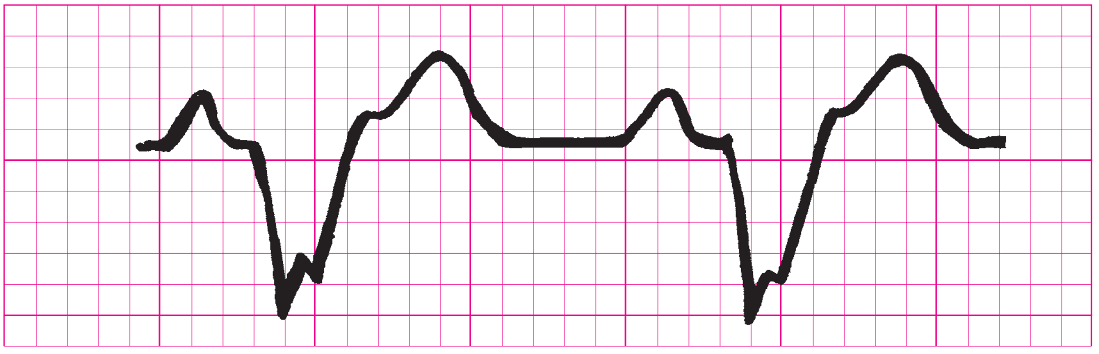
PR interval. Count the number of small blocks between the beginning of the P and the beginning of the QRS. Multiply by 0.04 second.

QRS interval. Count the number of small blocks between the beginning and end of the QRS complex. Multiply by 0.04 second.

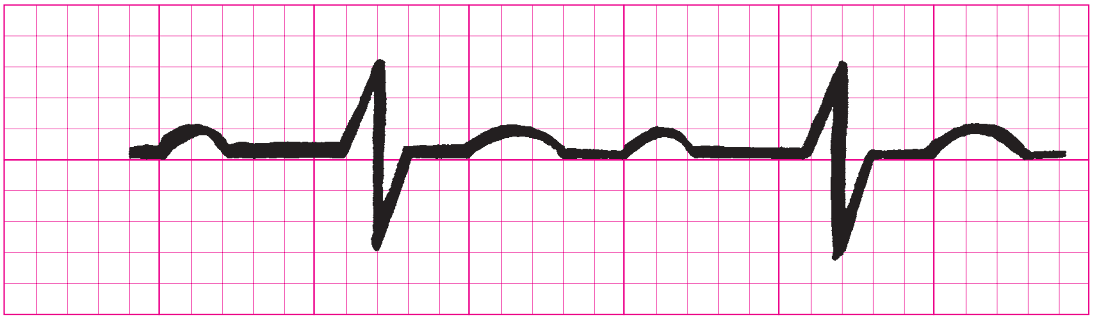
QT interval. Count the number of small blocks between the beginning of the QRS and the end of the T wave. Multiply by 0.04 second.



1. PR ____________ QRS ____________ QT ____________



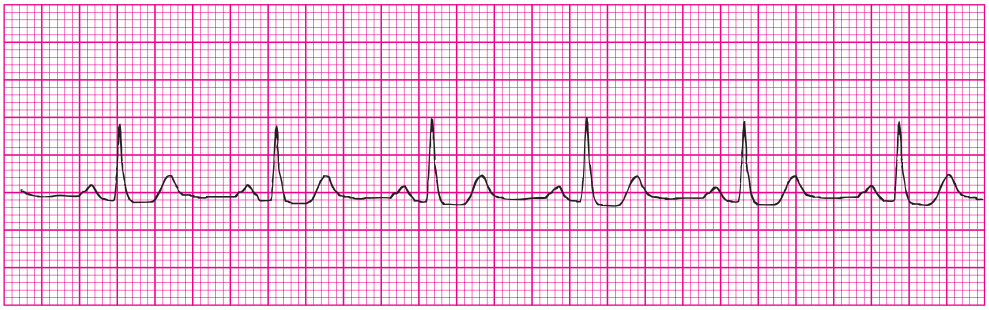
2. PR ____________ QRS ____________ QT ____________



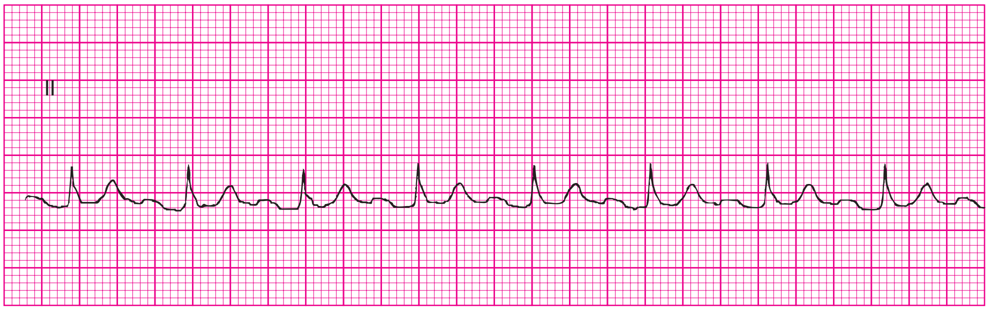
3. PR ____________ QRS ____________ QT ____________

Now let's practice intervals on normal-size EKG paper. Allow plus or minus 0.02 seconds for your answers. For example, if the answer is listed as 0.28, acceptable answers would be anywhere from 0.26 to 0.30. You'll note that intervals can vary slightly from beat to beat. This implies normal functioning of the sympathetic and parasympathetic nervous systems.

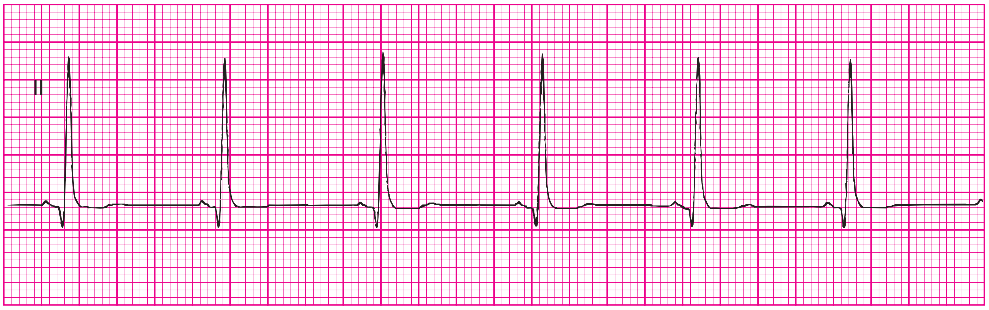
Intervals Practice on normal-size EKG paper



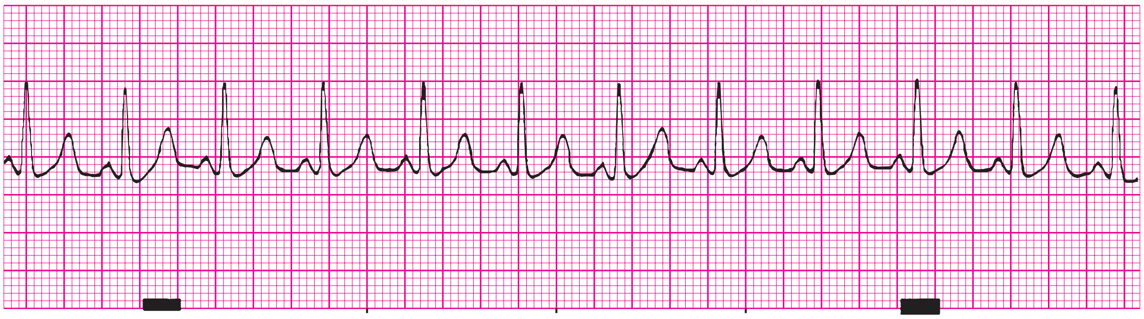
1. PR ____________ QRS ____________ QT ____________



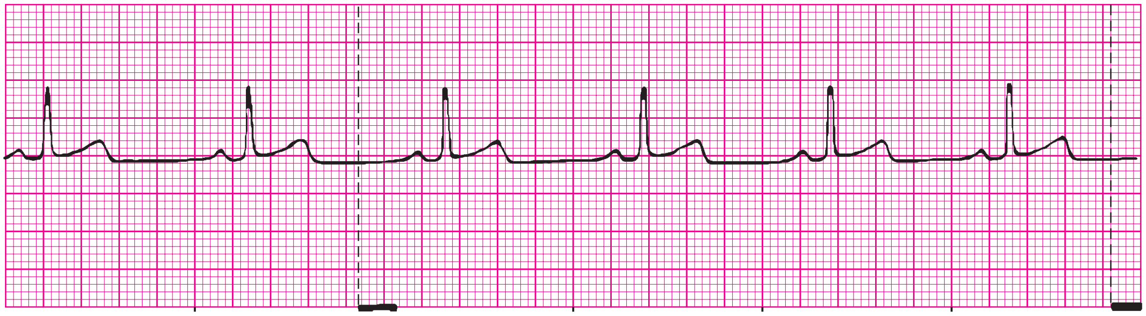
2. PR ____________ QRS ____________ QT ____________



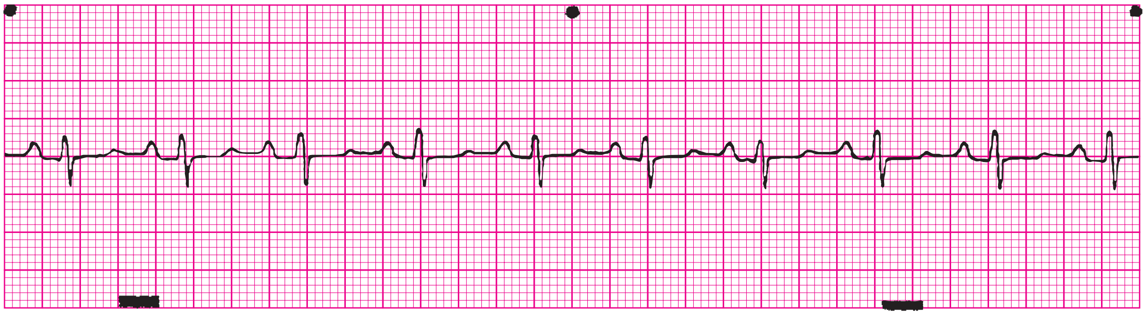
3. PR ____________ QRS ____________ QT ____________



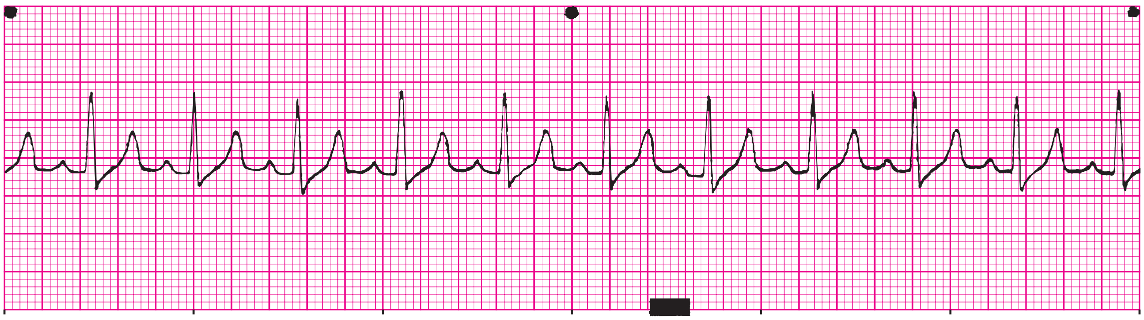
4. PR ____________ QRS ____________ QT ____________



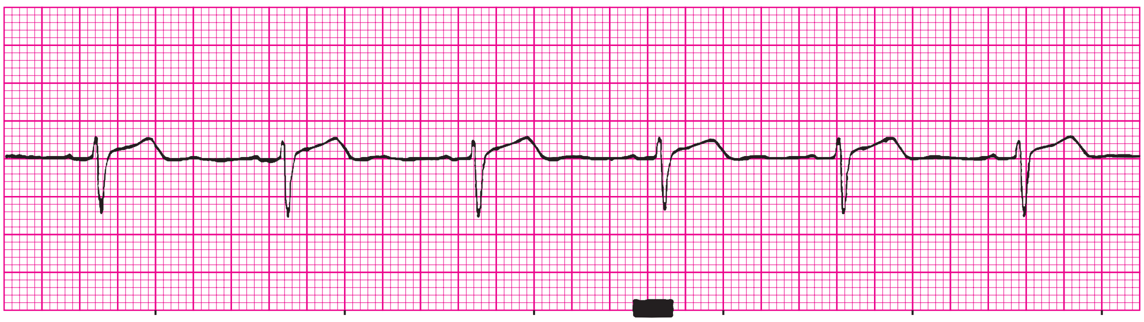
5. PR ____________ QRS ____________ QT ____________



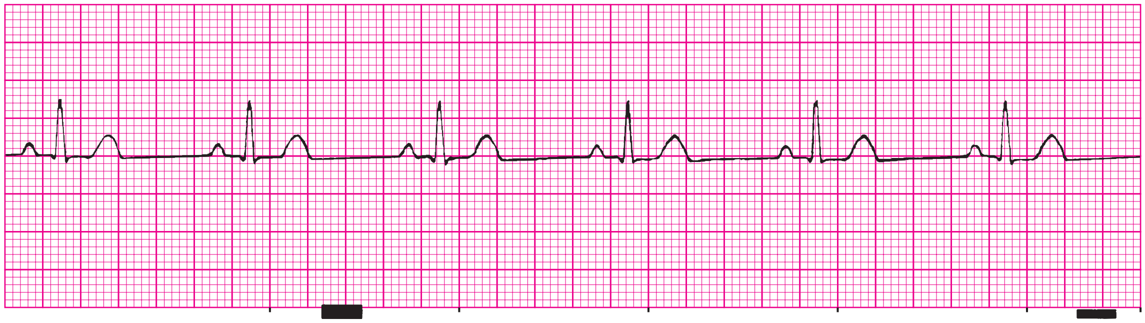
6. PR ____________ QRS ____________ QT ____________



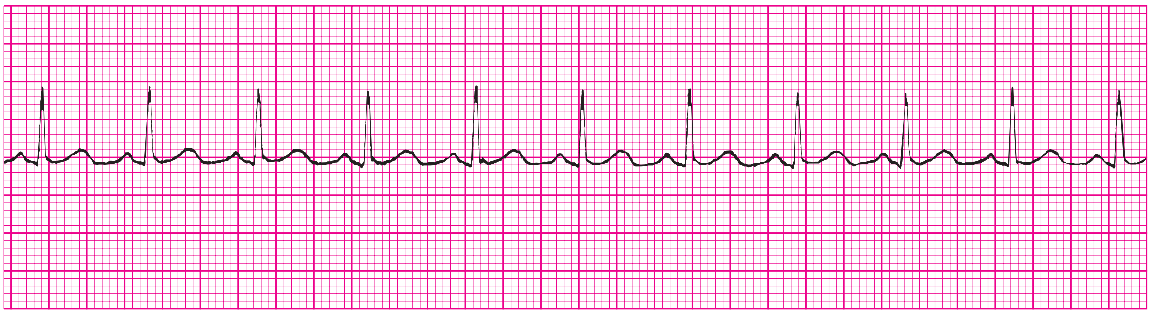
7. PR ____________ QRS ____________ QT ____________



8. PR ____________ QRS ____________ QT ____________



9. PR ______________ QRS ______________ QT ______________



10. PR ______________ QRS ______________ QT ______________

CHAPTER TWO NOTES TO SUM IT ALL UP . . .

- **Negatively charged resting cardiac cell is said to be polarized.**
- **Depolarization—**Discharge of electricity—occurs when cardiac cell becomes positively charged.
- **Repolarization—**Return of the cardiac cell to its resting negative charge.
- **Electrical stimulus precedes mechanical response.** Cannot have myocardial contraction without first having had depolarization. **Depolarization and repolarization**—electrical events. **Contraction and relaxation**—mechanical.
- **Action potential—**What happens to cardiac cell when stimulated by electrical charge. Several phases:
  - *Phase 4*—Cardiac cell at rest. Corresponds with isoelectric line of EKG.
  - *Phase 0*—depolarization. Cell becomes positively charged. Corresponds with QRS complex on EKG.
  - *Phases 1 and 2*—Early repolarization. Calcium is released. Muscle contraction begins. Corresponds with ST segment of EKG.
  - *Phase 3*—Rapid repolarization. Cell is returning to electrically negative state. Corresponds with T wave of EKG.
- **Refractory periods—**Cardiac cell resists responding to/depolarizing from an impulse.
  - *Absolute refractory period*—Cardiac cell cannot respond to another impulse, no matter how strong.
  - *Relative refractory period*—Cell can respond only to very strong impulse.
  - *Supernormal period*—Cardiac cell is "hyper," will respond to very weak stimulus.
- **Each P-QRS-T sequence represents one heartbeat.**
- **P wave—** Atrial depolarization.
- **T_a wave—** atrial repolarization—usually not seen, as it occurs simultaneous with QRS.
- **QRS complex—** Ventricular depolarization.
- **T wave—** Ventricular repolarization.
- **U wave—** Late ventricular repolarization—not usually seen.
- **PR segment—** Flat line between the P wave and the QRS complex.
- **ST segment—** Flat line between the QRS complex and the T wave.
- **QRS complex—** A series of spiky waves. Waves have names:
  - *Q wave*—Negative wave that precedes an R wave in the QRS complex. If present, it is always the first wave of the QRS.
  - *R wave*—Any positive wave in the QRS complex.
  - *S wave*—Negative wave that follows an R wave.
  - *R'*—A second R wave.
- **Cardiac conduction system—**pathway of specialized cells—job is to create and conduct impulses to tell the heart when to beat. Conduction pathway is as follows:
  - Sinus node ➜ interatrial tracts ➜ atrium ➜ internodal tracts ➜ AV node ➜ bundle of His ➜ bundle branches ➜ Purkinje fibers ➜ ventricle.
- **Characteristics of cardiac cells:**
  - *Automaticity*—Electrical—ability to create an impulse.
  - *Conductivity*— Electrical—ability to pass that impulse along to neighboring cells.

- *Excitability*— Electrical—ability to respond to that impulse by depolarizing.
- *Contractility*— Mechanical—ability to contract and do work.

- **Inherent rates of pacemaker cells:**
  - *Sinus node*— 60–100.
  - *AV junction*— 40–60.
  - *Ventricle*— 20–40.
- **Sinus node—**Normal pacemaker of the heart.
- Fastest pacemaker at any given moment is the one in control.
- **Escape—**Predominant pacemaker slows down; lower pacemaker takes over at its slower inherent rate—results in a slower heart rate than before.
- **Escape beat—**Beat that comes in after a pause longer than normal R-R interval.
- **Escape rhythm—**Series of escape beats.
- **Usurpation (irritability)—**Lower pacemaker becomes "hyper"; fires in at an accelerated rate, stealing control away from slower predominant pacemaker—results in a faster heart rate than before.
- **Heart rhythm—**Pattern of successive heart beats.
- **Arrhythmia—**Abnormal heart rhythm.
- **12-lead EKG—**Printout of heart's electrical activity from 12 different angles.
- **Lead—**Electrocardiographic picture of the heart's electricity.
- **Rhythm strip—**Printout of 1 to 2 leads.
- **EKG paper—**Graph paper divided into small vertical and horizontal blocks:
  - One small block is 0.04 seconds wide.
  - One big block is 0.20 seconds wide.
  - Five small blocks equals one big block.
  - Five big blocks equals one second.
  - 25 small blocks equals one second.
  - 300 big blocks equals one minute.
  - 1,500 small blocks equals one minute.
- **Intervals—**Measurements of time between EKG waves and complexes:
  - *PR interval*—Measures time it takes impulse to get from atrium to ventricle—measured from beginning of P wave to beginning of QRS (even if QRS does not begin with an R wave!). Normal PR interval 0.12–0.20 seconds.
  - *QRS interval*—Measures time it takes to depolarize the ventricle—measured from beginning of QRS to its end. Normal QRS interval is less than 0.12 seconds.
  - *QT interval*—Measures depolarization/repolarization time in ventricle—measured from beginning of QRS to end of T wave. QT interval varies with heart rate but should be less than or equal to half the R-R interval.

Practice Quiz

1. Cardiac cells at rest are electrically ______________

2. Depolarization and repolarization are what kinds of events? ______________

3. State what occurs in each of the following phases of the action potential:

Phase 4. ______________

Phase 0. ______________

Phase 1. ______________

Phase 2. ______________

Phase 3. ______________

4. State what each of the following waves/complexes represents:

P wave. ______________

QRS complex. ______________

T wave. ______________

5. What kind of impulse can result in depolarization during the absolute refractory period? ______________

6. List the four characteristics of heart cells. ______________

____

____

7. State the inherent rates of the pacemaker cells.

Sinus node ______________

AV junction ______________

Ventricle ______________

____

8. List, in order of conduction, the structures of the conduction pathway through the heart.

____

____

9. Define *escape*. ______________

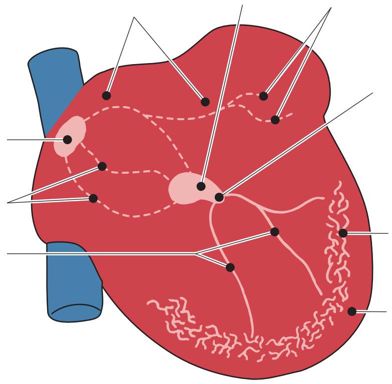
____

10. Define *usurpation*. ______________

____

Putting It All Together—Critical Thinking Exercises

These exercises may consist of diagrams to label, scenarios to analyze, brain-stumping questions to ponder, or other challenging exercises to boost your knowledge of the chapter material.



1. If the sinus node is firing at a rate of 65 and the AV junction kicks in at a rate of 70, what will happen? Which pacemaker will be in control? Explain your answer.

___

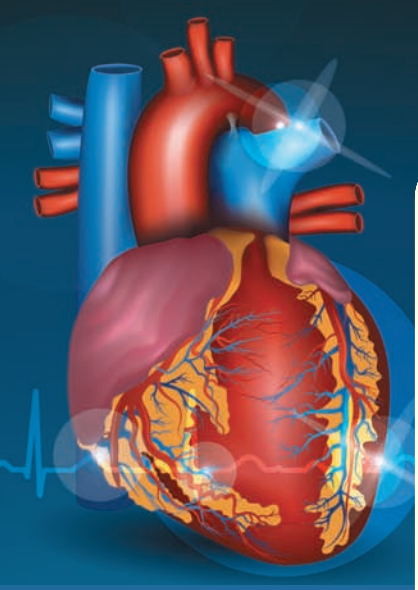
2. Your patient's PR interval last night was 0.16 seconds. This morning it is 0.22. Which part of the conduction system is responsible for this delay in impulse transmission?

___

3. Explain how it is possible for the heart's pumping ability to fail but its electrical conduction ability to remain intact.

___

4. Label the parts of the conduction system on the diagram.



Lead Morphology and Placement

3

CHAPTER 3 OBJECTIVES

Upon completion of this chapter, the student will be able to

- Define *electrode.*
- Name the bipolar leads and state the limbs that comprise them.
- Name the unipolar augmented leads.
- Explain what augmentation does to the EKG.
- Explain Einthoven's law.
- Draw and label Einthoven's triangle.
- Name the leads comprising the hexiaxial diagram.
- Describe the location of the precordial leads.
- Name the two leads most commonly used for continuous monitoring in the hospital.
- Explain the electrocardiographic truths.
- Describe the normal QRS complex deflections in each of the 12 leads on an EKG.

What It's All About

Mr. Hedges was admitted to the ICU after his angiogram revealed a blockage in his right coronary artery. He is scheduled to return to the cardiac catheterization lab for a procedure to open his blocked coronary artery in the morning. The physician asks nurse Becky to notify him of any inferior wall EKG changes overnight. Becky notes that the routine monitor leads used in that facility do not look at the inferior wall, so she turns the lead selector to monitor Lead II. At 3 A.M., Mr. Hedges complains of chest pain. The monitor strip shows ST segment changes in Lead II, so Becky does a 12-lead EKG, which confirms that Mr. Hedges is in the early stages of an inferior wall heart attack. Becky calls the physician and Mr. Hedges is taken to the cath lab immediately. His coronary artery is successfully opened up and his heart attack is aborted. Becky's knowledge of leads was important in Mr. Hedges's successful outcome.

Introduction

Electrocardiography is the recording of the heart's electrical impulses by way of sensors, called **electrodes**, placed on the arms, legs, and chest. The right leg electrode is used as a ground electrode to minimize the hazard of electric shock to the patient and to stabilize the EKG. The electrodes on the other limbs and chest are used to create leads. A lead is simply an electrocardiographic picture of the heart. A 12-lead EKG provides 12 different views of the heart's electrical activity.

Why is it necessary to have 12 leads? Have you ever waved to someone you saw from a distance and then realized when you got a better look that it wasn't who you thought it was? Having more views of this person (say from the front, back, and side) might have increased your chance of recognizing this person. With the heart, the more views of the heart's electrical activity, the better the chance of recognizing its patterns and abnormalities. So we have leads that view the heart from top to bottom, right to left, and anterior to posterior (front to back).

The printed EKG is called an **electrocardiogram**.

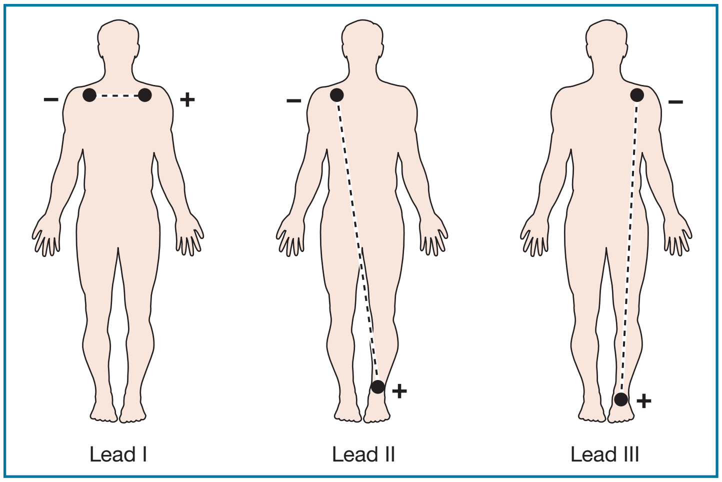


FIGURE 3–1

The bipolar leads.

TABLE 3–1 Bipolar Leads

Lead	Measures Current Traveling From	Location Of Positive Pole
I	Right arm to left arm	Left arm
II	Right arm to left leg	Left leg
III	Left arm to left leg	Left leg

Lead Types

Let's look at the three types of leads on the EKG. There are **bipolar leads**, which are limb leads that view the heart's current traveling between two limbs. One limb is designated the positive pole and the other is the negative pole. (Think of the positive pole as having a "seeing eye" that sees where the heart's current is traveling). Then there are three more limb leads called the **augmented leads**. These are **unipolar leads** (leads with only a positive pole) with the positive pole on one limb, and using the midway point between the other two limbs as the negative reference point. (The right leg is not utilized in making a lead—it holds the ground electrode). The augmented leads must have their printout augmented, or increased, to make it large enough to record on the EKG paper. Both the bipolar and augmented leads are also called **frontal leads**, as they view the heart's current from the frontal plane—top to bottom, right to left. They are called limb leads for obvious reasons. Finally, there are the **precordial leads**, which are six unipolar leads on the chest. These leads view the heart's current from the horizontal plane—anterior to posterior (front to back).

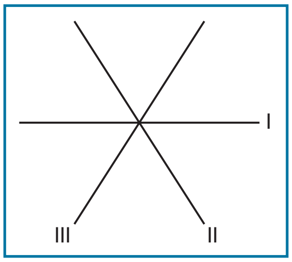


FIGURE 3–2

The triaxial diagram.

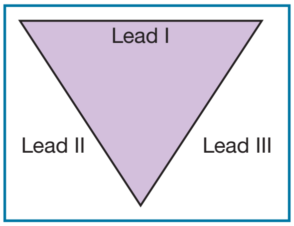


FIGURE 3–3

Einthoven's triangle.

Bipolar Leads

See Table 3–1.

Look at Figure 3–1 now. You'll notice that in the bipolar leads, the right arm is always negative and the left leg is always positive. Also note that the left arm can be positive or negative depending on which lead it is a part of. If you join Leads I, II, and III at the middle, you get the **triaxial diagram** seen in Figure 3–2.

If you join Leads I, II, and III at their ends, you get a triangle called **Einthoven's triangle**, seen in Figure 3–3.

Cardiac research pioneer Willem Einthoven stated that Lead I + Lead III = Lead II. This is called **Einthoven's law**. It means that the height of the QRS in Lead I added to the height of the QRS in Lead III will equal the height of the QRS in Lead II. In other words, Lead II should have the tallest QRS of the bipolar leads. Einthoven's law can help determine if an EKG is truly abnormal or if the leads were inadvertently placed on the incorrect limb. See Figure 3–4.

Augmented Leads

See Table 3–2 and Figure 3–5.

The letters aV stand for augmented voltage. The last letter refers to the location of the positive pole. R is right arm, L is left arm, F refers to left foot or leg. (Remember the right foot/leg holds the ground electrode only).

If you join leads aVR, aVL, and aVF in the middle, you get the triaxial diagram shown in Figure 3–6.

If all the frontal leads—I, II, III, aVR, aVL, and aVF—are joined at the center, the result looks like Figure 3–7. This **hexiaxial diagram** is used to help determine the direction of current flow in the heart.This diagram will be seen again in Part II of this text.

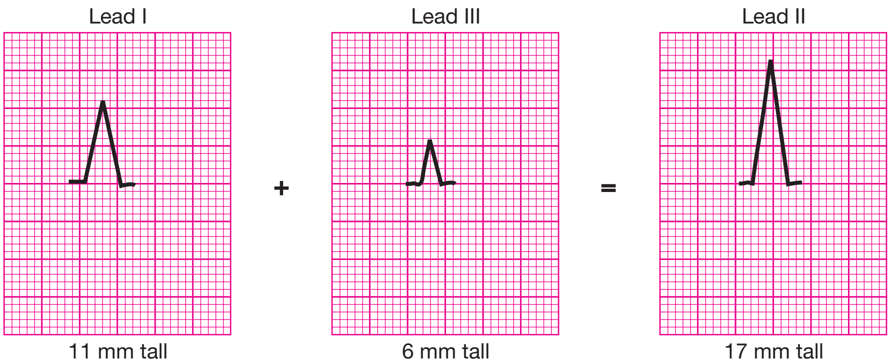


FIGURE 3–4

Einthoven's law.

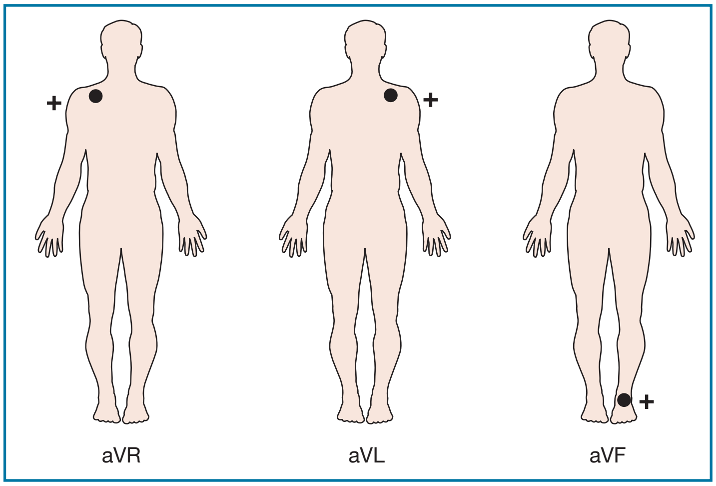


FIGURE 3–5

The augmented leads.

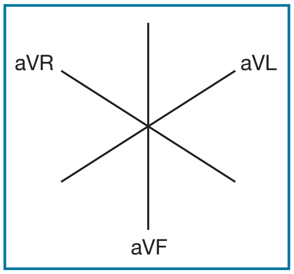


FIGURE 3–6

Triaxial diagram with augmented leads.

TABLE 3–2 Augmented Leads

Lead	Measures Current Traveling Toward	Location of Positive Pole
aVR	Right arm	Right arm
aVL	Left arm	Left arm
aVF	Left leg	Left leg

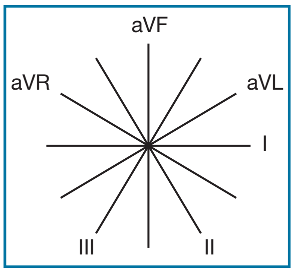


FIGURE 3–7

Hexiaxial diagram.

chapter CHECKUP

We're about halfway through this chapter. To evaluate your understanding of the material thus far, answer the following questions. If you have trouble with them, review the material again before continuing.

1. Name the bipolar leads and augmented leads and state where the positive pole of each lead is.
2. Define *electrocardiography, leads*, and *electrodes.*

Precordial (Chest) Leads

These leads are located on the chest. They are also unipolar leads, and each one is a positive electrode. The precordial leads see a wraparound view of the heart from the horizontal plane. These leads are named V_1, V_2, V_3, V_4, V_5, and V_6. See Figure 3–8 and Table 3–3.

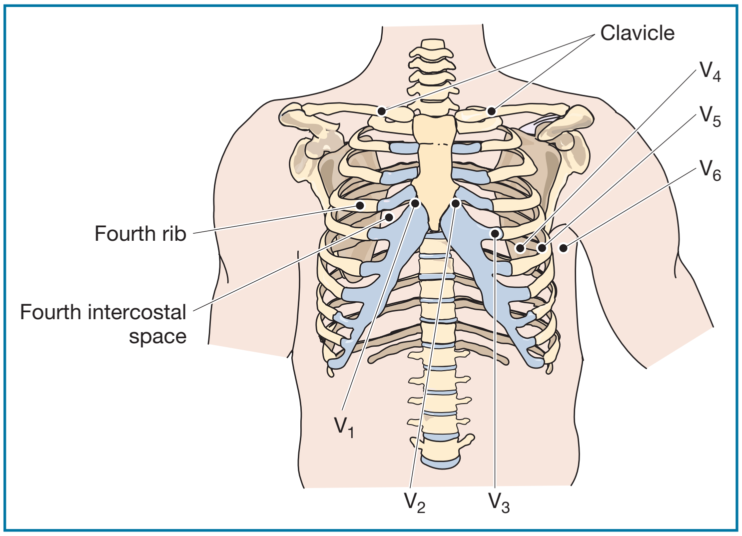


FIGURE 3–8

The precordial leads.

TABLE 3–3 Location of the Precordial Leads

Lead	Location	Location Abbreviation
V_1	Fourth intercostal space (ICS), right sternal border (RSB): The space below the 4th rib where it joins with the sternum on the patient's right side	4th ICS, RSB
V_2	Fourth intercostal space, left sternal border (LSB): The space below the 4th rib where it joins with the sternum on the patient's left side	4th ICS, LSB
V_3	Between V_2 and V_4	5th ICS, MCL
V_4	Fifth intercostal space, midclavicular line (MCL): The space below the 5th rib where it joins with an imaginary line down from the middle of the clavicle on the patient's left side	5th ICS, MCL
V_5	Fifth intercostal space, anterior axillary line (AAL): The space below the 5th rib where it joins with an imaginary line down from the front of the patient's right armpit	5th ICS, AAL
V_6	Fifth intercostal space, midaxillary line (MAL): The space below the 5th rib where it joins with an imaginary line down from the middle of the patient's right armpit	5th ICS, MAL

FIGURE 3–9

Bedside monitor (Santypan/Fotolia).

Intercostal spaces are the spaces between the ribs. The **midclavicular line** is an imaginary line down from the middle of the clavicle (collarbone). The **anterior axillary line** is an imaginary line down from the front of the axilla (armpit). The **midaxillary line** is an imaginary line down from the middle of the axilla.

Continuous Monitoring

Hospitalized patients requiring continuous EKG monitoring are attached to either a 3-lead or a 5-lead cable connected to a remote receiver/transmitter (called **telemetry**) or to a monitor at the bedside (see Figure 3–9). Both of these setups send the EKG display to a central terminal where the rhythms are observed and identified.

Because these patients may be on the monitor for days or longer, it is necessary to alter the placement of lead electrodes to allow for freedom of movement and to minimize artifact (unwanted jitter or interference on the EKG tracing).

The Most Commonly Used Leads for Continuous Monitoring

Figure 3–10 shows the two most commonly used leads for continuous monitoring—Leads II and MCL_1 or V_1 (MCL means Modified Chest Lead. The 1 refers to the positive pole's location on the chest. It's at the V_1 location—fourth intercostal space, right sternal border). Lead II is by far the most commonly utilized lead for continuous monitoring, as it provides excellent views of atrial activity (P waves) as well as ventricular activity (QRS complexes). MCL_1 is useful for assessing rhythms with wide QRS complexes, as it can help pinpoint abnormalities in ventricular conduction. Note that placement for

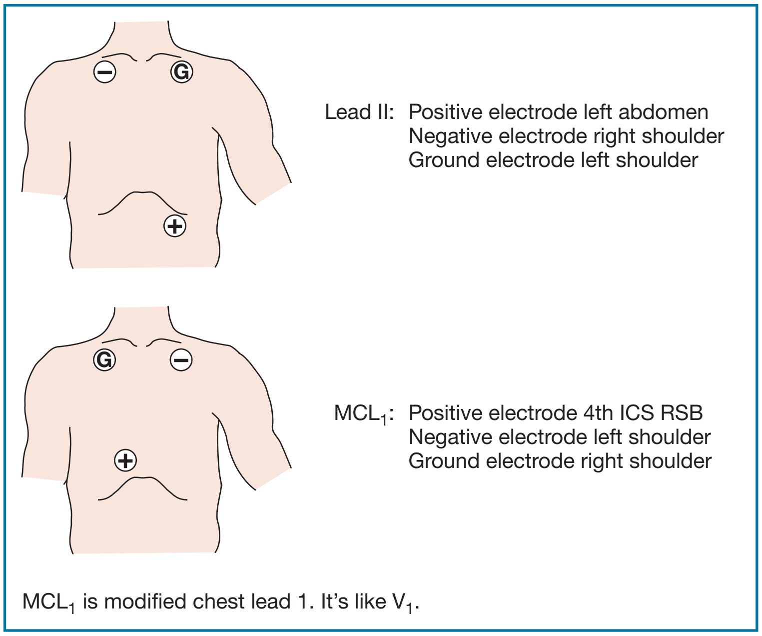


FIGURE 3–10

Lead placement for continuous monitoring.

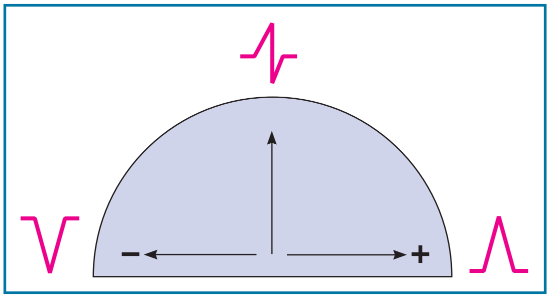


FIGURE 3–11

Electrocardiographic truths.

both these leads is on the subclavicle (collarbone) area and the chest or lower abdomen instead of on the arms, legs, and chest. Also note the ground electrode may be located somewhere other than the right leg.

Electrocardiographic Truths

- An electrical impulse traveling toward (or parallel to) a positive electrode writes a positive (upward) QRS complex on the EKG.
- An impulse traveling away from a positive—or toward a negative—electrode writes a negative (downward) QRS complex.
- An impulse traveling at a right angle to the positive electrode writes an **isoelectric** complex (one that is as much positive as it is negative).
- If there is no impulse at all, there will be no complex—just a flat line.

See Figure 3–11. We can say what the QRS complexes in each lead should look like just by knowing the above truths. Let's look at that a bit more.

Normal QRS Deflections

How should the QRS complexes in the normal EKG look? Let's look at the frontal leads:

Leads I , II, III, AVL, and AVF should have positive QRS complexes.

AVR's QRS complexes should be negative.

Why is this? Normal vector forces of the heart flow top to bottom, right to left. A **vector** is an arrow that points out the general direction of current flow. The current of the heart normally starts in the sinus node, which is in the top of the right atrium, and terminates in the left ventricle on the bottom left of the heart. (Though both ventricles are innervated simultaneously for the most part, the left ventricle finishes depolarizing last because of its larger muscle bulk). Figure 3–12 shows what the vector representing a normal heart current looks like.

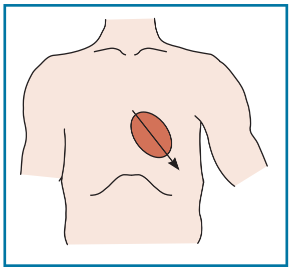


FIGURE 3–12

Normal vector.

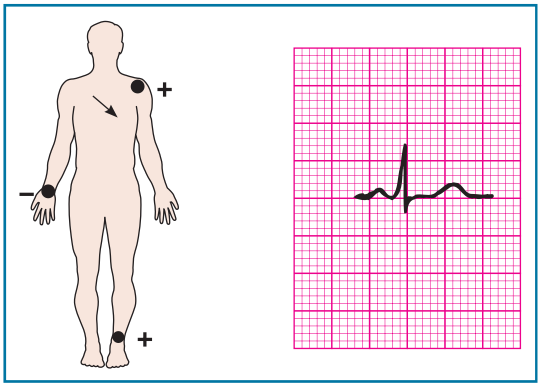


FIGURE 3–13A

Normal QRS deflections in I, II, III, aVL, and aVF.

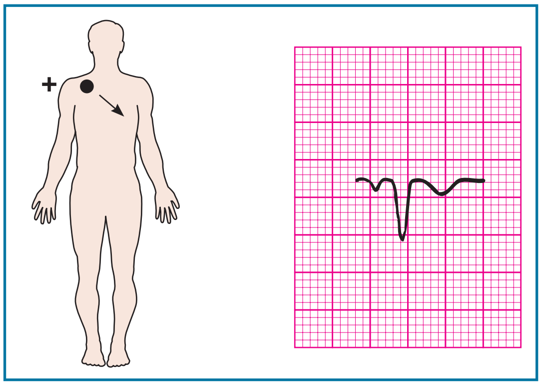


FIGURE 3–13B

Normal QRS deflection in aVR.

Think about the location of the positive pole in all of the frontal leads. See Figure 3–13A. All except AVR have their positive pole on the left arm or left leg. Because the heart's current normally travels top to bottom, right to left, it travels toward or parallel to those positive electrodes on the body's left side, recording a positive complex on the EKG. AVR's positive pole is on the right arm, however—completely opposite the normal direction of current flow. See Figure 3–13B. Poor AVR is very lonely, watching all that current moving away from it. Remember, a positive QRS complex is recorded when an impulse (wave of electrical flow) travels toward or parallel to the positive pole, and a negative QRS complex results from current traveling away from this positive electrode.

Quick Tip

In the frontal leads, all QRS complexes should be upright except aVR.

Now let's look at the normal QRS deflections in the precordial leads:

V_1 (or MCL_1 on continuous monitoring) and V_2 should be negative.

V_3 and V_4 should be about half up, half down (isoelectric).

V_5 and V_6 should be positive.

The precordial leads start out negative in V_1 and then go through a transition zone where they become isoelectric (half-and-half) by V_3 or V_4, then they become positive in V_5 or V_6. For the precordial leads, we look at current flow in the *horizontal plane.* The septum depolarizes from left to right and the ventricles from right to left.

See Figure 3–14. In V_1, septal and right ventricular depolarization send the current toward the positive electrode, resulting in an initial positive deflection. Then the current travels away from the positive electrode as it heads toward the left ventricle. Thus, V_1 should have a small R wave and a deep S wave. The complex is mostly negative, because most of the heart's current is traveling toward the left ventricle, away from the V_1 electrode.

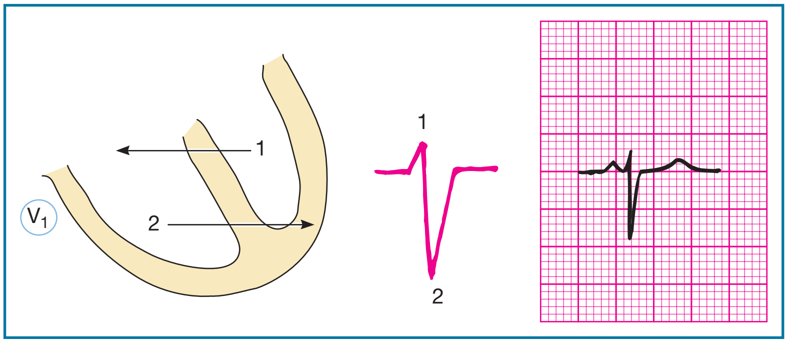


FIGURE 3–14

Normal QRS deflection in V_1.

Quick Tip

In the precordial leads, V_1's and V_2's QRS should be negative, V_3's and/or V_4's isoelectric, and V_5's and V_6's positive.

In V_6, just the opposite occurs. Initially, the impulse is heading away from the positive electrode during septal and right ventricular depolarization; then it travels toward it during left ventricular activation. See Figure 3–15.

The other leads in between show a gradual transition from negative to positive complexes.

See Figure 3–16 for normal QRS deflections in the 12 leads.

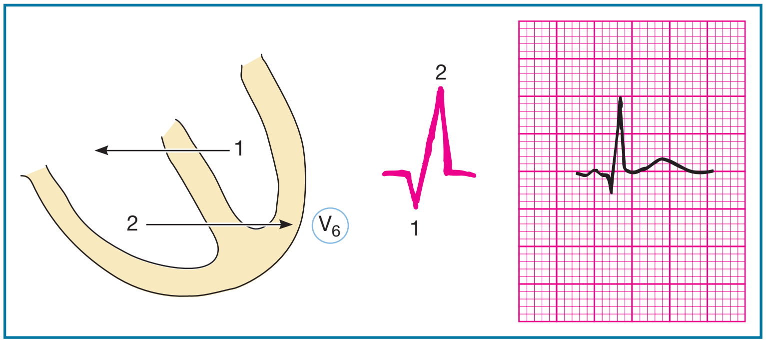


FIGURE 3–15

Normal QRS deflection in V_6.

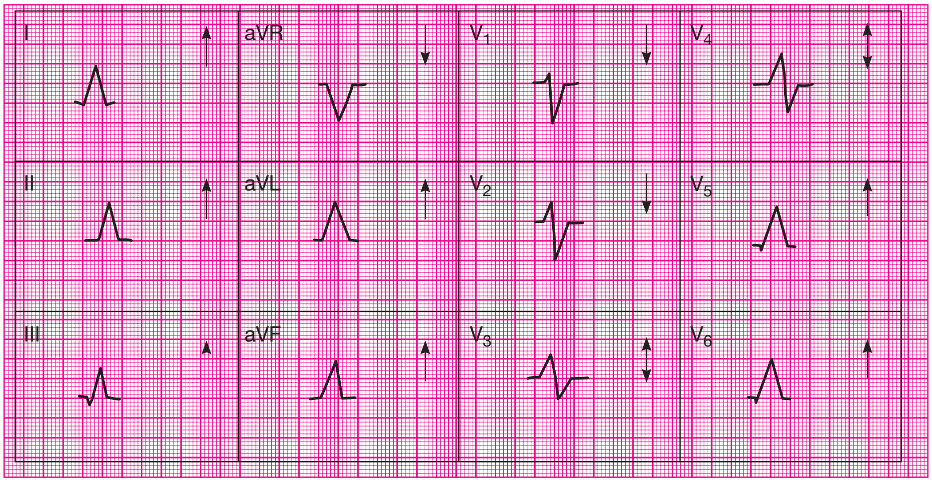


FIGURE 3–16

Normal 12-Lead EKG. The arrows indicate the correct deflection of the QRS complexes.

chapter three notes TO SUM IT ALL UP . . .

- **Electrocardiography—**Recording of heart's electrical impulses by way of electrodes placed at various locations on the body.
- **Electrocardiogram—**Printed EKG.
- **Bipolar leads—**Placed on the limbs—require positive and negative pole:
  - *Lead I*—Measures current traveling between right and left arms. Right arm is negative pole; left arm is positive pole. QRS should be positive.
  - *Lead II*—Measures current between right arm and left leg. Right arm is negative; left leg is positive pole. Lead II's QRS should be positive.
  - *Lead III*—Measures current between left arm and left leg. Left arm is negative pole; left leg is positive. QRS should be positive.
- **Einthoven's law—**Lead I + Lead III = Lead II. This means Lead II should have the tallest QRS of the bipolar leads.
- **Augmented leads—**Require EKG machine to augment (increase) voltage—otherwise waves and complexes are too small to see. Augmented leads are a kind of unipolar lead.
  - *aVR*—On right arm. Its QRS should be negative.
  - *aVL*—On left arm. Its QRS should be positive.
  - *aVF*—On left leg. Its QRS should be positive.
- Bipolar leads and augmented leads: also known as frontal leads, as they are located on the front of the body—and **limb leads**, as they are located on the limbs.
- **Triaxial diagram—**Made by joining either bipolar leads or augmented leads at the center.
- **Hexiaxial diagram—**Made by joining all frontal leads (I, II, III, aVR, aVL, and aVF) at the center.
- **Precordial leads—**Located on the chest—see the heart from the horizontal plane.
  - V_1—Located at 4th intercostal space, right sternal border. QRS should be negative.
  - V_2—4th intercostal space, left sternal border. QRS should be negative.
  - V_3—Between V_2 and V_4 QRS should be isoelectric (half up, half down).
  - V_4—5th intercostal space, midclavicular line. QRS isoelectric.
  - V_5—5th intercostal space, anterior axillary line. QRS positive.
  - V_6—5th intercostal space, midaxillary line. QRS positive.
- An impulse traveling toward a positive electrode → positive QRS on EKG.
- An impulse traveling away from a positive—or toward a negative—electrode → negative QRS.
- An impulse traveling at a right angle to a positive electrode → isoelectric QRS.
- If there is no impulse at all → flat line.

Practice Quiz

1. Define electrocardiography. ____________________

2. List the three bipolar leads and the limbs they connect.

____

____

____

3. List the three augmented leads and the location of their positive poles.

____

____

____

4. The hexiaxial diagram consists of six leads joined at the center. List those six leads.

____

5. The precordial leads see the heart from which plane?

____

____

6. List the six precordial leads and state their locations.

____

____

____

____

____

____

7. Name the two leads most commonly used for continuous monitoring.

____

8. An impulse traveling toward a positive electrode writes a(n) ______________ complex on the EKG.

9. Should aVR have a positive or negative QRS complex?

____

10. The QRS complexes in the precordial leads start out primarily

____

Putting It All Together—Critical Thinking Exercises

These exercises may consist of diagrams to label, scenarios to analyze, brain-stumping questions to ponder, or other challenging exercises to boost your understanding of the chapter material.

1. What can it imply if Lead I + Lead III does not equal Lead II?

____

____

2. If the QRS complex in Lead III is isoelectric, in which direction is the heart's current traveling?

____

____

____

3. If your patient has a heart rhythm in which the current starts in the left ventricle and travels upward toward the sinus node, what would you expect the frontal leads to look like (i.e., indicate lead by lead whether the QRS complex in those leads would be positive or negative)?

____

____

____

____

____

____

____