2

Chambers, Valves and Vessels

Quick Look

If you could have it all with regards to electrocardiogram interpretation, what might that look like? Participants asked this question in ECG courses tend to want to quickly identify a cardiac rhythm strip competently and confidently.

But they also want to make sense of ECGs. To connect the rate, pattern and shape of the ECG with a patient's current clinical status. To recognize which cardiac rhythms are benign and which rhythms demand urgent attention. Some even want to be able to link components of an ECG to a patient's prognosis.

You can have it all. If you want to quickly identify cardiac rhythms, the last five chapters will suffice. If you want to put the whole picture together and make sense of ECGs, begin right here and work your way through. The journey's a bit longer but well worth it.

The first three chapters of this book provide the basics of cardiac anatomy and physiology. This chapter sets the stage, covering the anatomical structures of the heart. This may be just a good review. Let's begin.

In my beginning is my end.

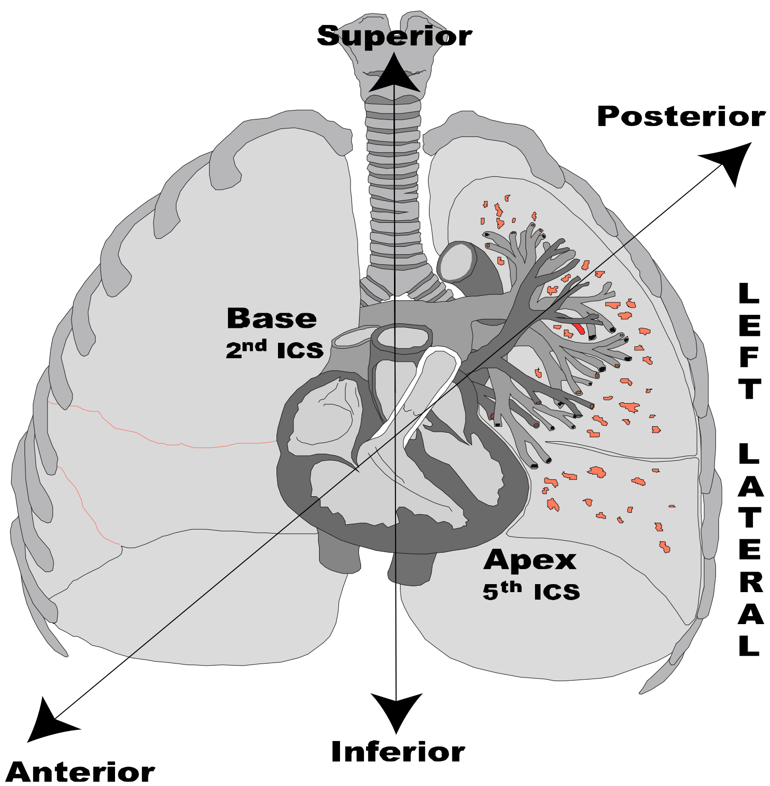
T.S. Eliot

Overview

The heart is a wondrous organ about the size of your fist, weighing in at less than a pound (about 400 grams). Each day, the adult heart beats over 100,000 times, delivering 7500 liters of blood to the tissues of the body. The heart is dynamic, ever sensitive and responsive to mechanical, chemical and electrical stimuli. It continuously fluctuates in rate and force in response to our physiologic and environmental needs.

Situated in the mediastinum directly behind the sternum, approximately 2/3 of the heart is left of the sternal border, resting on the diaphragm. The heart's apex is at the bottom of the heart pointing left near the 5th intercostal space (ICS). The base of the heart is located near the 2nd intercostal space to the right of the sternum.

Figure 2.1 Location and Views



The heart is not positioned straight up. Rather, it sits on its right border (the base of the septum is pulled to the left) with the right chamber rotated anteriorly. Visualize the patient's right lateral border of the heart being pulled forward. In turn, this would bring the left border of the heart more posterior. Nevertheless, the larger left ventricle occupies the majority of the anterior, lateral and inferior surfaces of the heart.

Table 2.1 Views of the Heart

Perspectives	Heart Chambers
Anterior	Left Ventricle and Left Atrium
Left Lateral*	Left Ventricle and Left Atrium
Inferior**	Left and Right Ventricle
Right Lateral	Right Ventricle
Posterior	Left and Right Ventricle

**lateral MIs generally refer to left lateral MI*
*** only about 40% of inferior MIs are right ventricular infarctions*

So, when you are told that your patient is experiencing an anterior myocardial infarction (MI), what ventricle is most likely affected? How about an inferior MI? An anterolateral MI? Take a look at figure 1.1 and table 1.1.

A 12 Lead ECG provides a fairly good electrical picture of the left side of the heart. The right side of the heart is somewhat under served. If the 12 Lead suggests any pathology to the inferior view of the heart (left and right ventricle), 3 additional lead views should be added to map out the right lateral and posterior views. The resulting 15 lead ECG provides a more complete three dimensional picture of the heart.

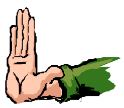
The inferior view of the heart includes the right ventricle and the heart's apex (left ventricle). About 40% of inferior MIs are right ventricular infarctions. The anterior and lateral (left lateral) views of the heart are of the left ventricle and left atrium.

The Mechanical Structures of the Heart

The mechanical structures of the heart include the heart's layers, chambers, septum, valves, and the major vessels (including the coronary arteries). Each of these structures contribute to the effective ejection of blood - the primary purpose of the heart. The electrical components and pathways will be addressed separately in Chapter 3.

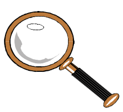
Layers

The heart is encased in two protective layers (refer to Figure 1.2 on the next page). The outer layer, the pericardial sac, covers the heart. It folds in on itself at the aorta forming the epicardial surface of the heart. Between these layers is a small amount of fluid that provides a non-stick surface between these layers.



Pericarditis, an infection within the pericardial sac, can cause increased friction between the inner surfaces of these layers. Chest discomfort is common. A friction rub, a sound similar to that produced by rubbing leather together - may also result. Note also that an accumulation of relatively small amounts of fluid (200 ml) in this pericardial sac - **pericardial effusions** - can straight jacket the heart's ability to contract. This condition called **cardiac tamponade** may result in little or no cardiac output.

The epicardium forms the outer layer of the heart. The myocardium forms the middle layer and the endocardium the innermost layer of the heart. The coronary arteries provide blood to the heart tissues, carrying blood first across the epicardium, then the myocardium and finally terminating in the endocardium.



The endocardium claims the dubious position as the terminus for the coronary arteries. Since the coronary arteries begin along the epicardial surface, enter the myocardium and terminate in the endocardium, myocardial ischemia rarely occurs without endocardial ischemia. While the endocardium is damaged in most every myocardial infarction, the epicardium's location in the blood flow hierarchy increases its safety factor.

The muscular myocardium is the thickest layer and the workhorse of the heart. It is composed of specialized muscle and electrical cells that are able to conduct an electrical impulse quickly and contract forcefully. The endocardium has a smooth inner surface to allow blood to flow easily through the heart's chambers. The heart's valves are part of the endocardium.

The endocardium releases hormones such as:

- endocardin, a substance that prolongs myocardial contraction;
- atrial natriuretic factor (ANF), released by the atria to oppose the activity of epinephrine, endothelin and the renin-angiotensin system
- brain natriuretic peptide (BNP) which is released by the ventricles upon ventricular distention having similar effects to ANF.

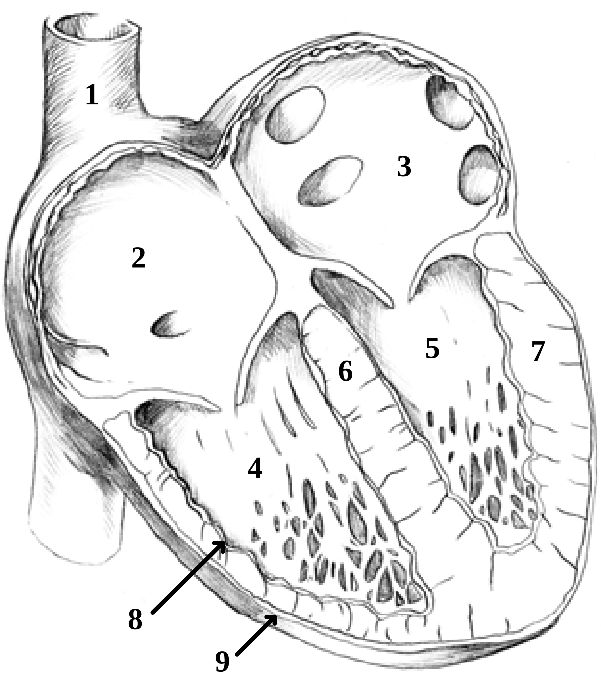
The heart is not just a pump but also an endocrine organ!

Chambers

The chambers of the heart are the main drivers within an intricate pathway, delivering blood to the lungs for gas exchange and enriching the body's cells with oxygen. The contracting and relaxing chambers facilitate varying pressure gradients that drive a resting cardiac output of five litres of blood per minute.

As the ventricles contract, the pressure in the ventricles overcomes the pressure of the aorta or pulmonary arteries, resulting in the valves opening and blood ejection. Similarly, as the ventricles relax and open, the resulting falling pressure created within the ventricles draws blood from the atria. Essentially, blood is sucked into the ventricle. In a healthy heart, approximately 65-85% of ventricular blood volume is provided during early diastole. Atrial diastole tops off the remaining 15-35% (atrial kick).

Figure 2.2 Chambers and Layers



1. ____________________

2. ____________________

3. ____________________

4. ____________________

5. ____________________

6. ____________________

7. ____________________

8. ____________________

9. ____________________

The heart consists of 4 chambers - 2 atria and 2 ventricles. The smaller atria are about 1/3 the size and volume of the ventricles. The left ventricle is the largest chamber of the heart, with about 3 times more muscle mass than the right ventricle. Both ventricles share a similar volume capacity. Due to the predominant size of the left ventricle, it is not surprising that 70% of all myocardial infarctions occur within the left ventricle.

Labels to figure 1.1: ***1.*** *superior vena cava;* ***2.*** *right atrium;* ***3.*** *left atrium;* ***4.*** *right ventricle;* ***5.*** *left ventricle;* ***6.*** *septum;* ***7.*** *myocardium;* ***8.*** *endocardium;* ***9.*** *epicardium*

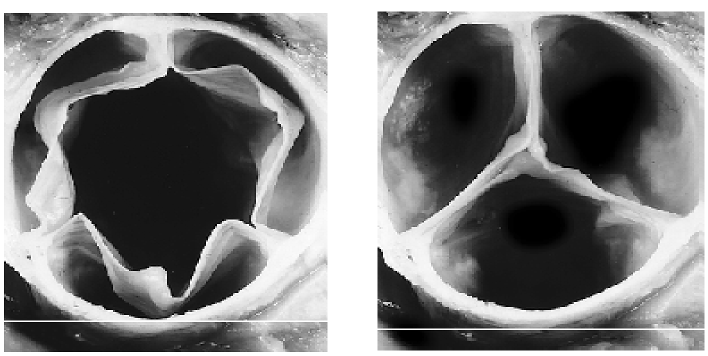
Heart valves ensure the forward flow of blood by closing off any back end routes. The atria do not share this advantage. The absence of valves between the venous system and the atria means that a small amount of blood is ejected back into the venous system with atrial contraction. With certain cardiac rhythms (i.e. 3rd degree AV Block, ventricular tachycardia and junctional rhythms), the timing of atrial contraction coincides with ventricular contraction and the closure of the AV valves (tricuspid and bicuspid). As a result, the atrial contraction delivers blood primarily back into the venous system causing the jugular veins to pulsate. The pulsations along the jugular veins are called **canon A waves**. This finding is sometimes useful when attempting to identify various challenging rhythms.

Discussions of the heart often refer to two hearts - a right and a left heart. Structurally, this is due to a thick layer of connective tissue called the septum that separates the left and right heart. Functionally, the right heart pumps deoxygenated blood to the lungs while the left heart pumps oxygenated blood to the body. When either the left or right side of the heart is unable to pump an adequate volume of blood, heart failure ensues that causes both decreased output and a backward volume buildup.

Valves

Valves act as gates ensuring unidirectional blood flow. They are located between the atria and ventricles as well as between the ventricles and the major arteries. The atrioventricular (AV) valves lie between the atria and the ventricles of the right and left heart. The ventricles eject blood through semilunar valves composed of 3 cusps.

Figure 2.3 Semilunar Valve (aortic or pulmonic)



Open **Closed**

The aortic and pulmonic semilunar valves are pictured in Figure 1.3. The three leaves of the semilunar valves are billowed closed during ventricular diastole as arterial pressure becomes greater than the pressure within the ventricles. The semilunar valves ensure forward flow of arterial blood ejected from the ventricles.

The atria and ventricles are separated by the tricuspid valve (3 leaf) in the right heart and the bicuspid or mitral valve (2 leaf) in the left heart. Blood ejected from the ventricles pass through the semilunar valves (see Figure 1.3), the pulmonic valve into the pulmonary arteries and the aortic valve into the aorta. Pressure within a ventricle or artery catches the cusps of a valve - like a parachute - closing the valve and preventing back flow.

Figure 2.4 The Heart's Valves (superior view)

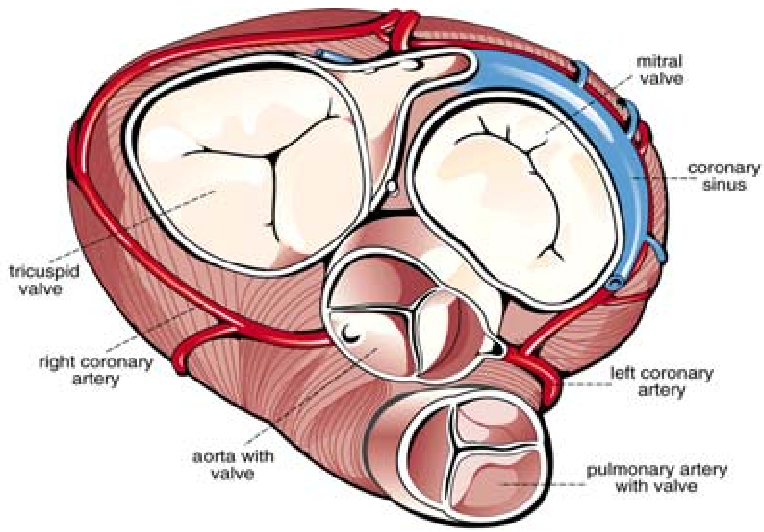


Figure 1.4 depicts the valves of the heart as viewed from above the heart.

The valves are composed of similar components: leaflets; annulus - a fibrous ring that encircles the valve; and chordae tendaneae – fibrous ligaments that connect to the papillary muscles. The papillary muscles flex when the ventricles contract to stabilize the AV valves. Note that an MI may weaken papillary muscles or rupture the chordae tendaneae, resulting in a heart murmur.

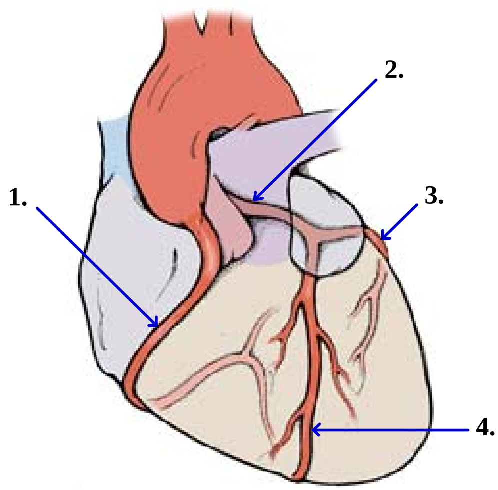
While heart murmurs may suggest valvular pathology, heart sounds also suggest normal function. The closing of the AV valves produce the classic **S1** sound, heard at the beginning of ventricle systole ('lub' of lub-dub). Subsequently, as the ventricles begin to relax (diastole), the semilunar valves close producing the **S2** heart sound ('dub').

Other causes of heart murmurs include age related changes to the valves such as the formation of calcium deposits and the stenosis of the valve leaflets or cusps. An impaired mitral valve, for example, could result in reduced blood volume being ejected from the left ventricle due to regurgitation of blood back into the atrium. This can eventually lead to left atrial hypertrophy and pulmonary hypertension.

Coronary Arteries

In order to beat over 100,000 times daily, the heart muscle requires a substantial blood and oxygen supply. The coronary arteries distribute the oxygen and nutrients necessary to provide energy to meet the workload demands of the heart. Even at rest, the cardiac cells extract 75% of the oxygen from the coronary arteries to meet energy demands. Essentially, the heart is entirely dependant on increased coronary artery blood flow to meet any increases in cardiac workload.

Figure 2.5 Coronary Arteries



1. ____________________
2. ____________________
3. ____________________
4. ____________________

About 4-5% of the body's blood volume is contained by the heart's arteries and veins. This is a large volume considering that the heart comprises less than 1% of an adult's body mass.The heart's blood supply is provided mostly as the heart relaxes and dilates during diastole. This is unique - most organs receive pulsations of new oxygen-rich blood during cardiac systole (contractile phase of the heart).

The quantity of blood circulating through the coronary arteries is directly related to the coronary perfusion pressure, the difference between aortic diastolic pressure and central venous pressure (right atrial pressure). During events with increased central venous pressure and lower aortic diastolic pressure (i.e. right ventricular infarction) coronary perfusion often suffers.

Labels to figure 1.5: ***1.*** *RCA - right coronary artery;* ***2.*** *left main;* ***3.*** *circumflex;* ***4.*** *LAD - left anterior descending;*

The **right coronary artery** (RCA), sprouts off of the aorta superior to the aortic valve, primarily serving the right ventricle and the right atria. In about 50% of the population, the RCA branches early on to form the conus artery to further serve the right side of the heart. The RCA serves the right ventricle, the right atrium, the SA node (50-60% of people) and the AV node (90% of people). Note that the AV node and the Bundle of His are often served by both the RCA and the circumflex artery.

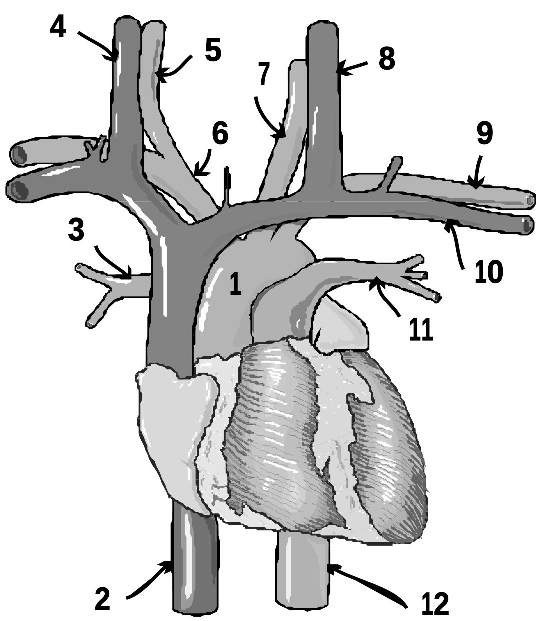
The **left main** begins at the left border of the aorta opposite the entrance to the RCA. The left main soon splits into 2 arteries: 1) the **circumflex** wraps around the surface of the left heart; and 2) the **left anterior descending** artery travels down the anterior surface of the left ventricle. The circumflex also serves the SA node (40-50% of people) and the AV node (10% of people).

The coronary veins exit into the right atrium via the coronary sinus. A one-way valve covers the coronary sinus, called the Thebesian valve (now this is definitely trivia).

Major Vessels

Several major vessels enter and exit the heart. The arteries carry blood away from the heart while the veins bring blood to the heart. While memorizing the major vessels is unnecessary, having a basic picture of the major vessels is clinically important.

Figure 2.6 Major Vessels



1. Aortic Arch
2. Inferior Vena Cava
3. Right Pulmonary Artery
4. Right Jugular Vein
5. Right Carotid Artery
6. Bracheocephalic Artery
7. Left Carotid Vein
8. Left Jugular Vein
9. Left Subclavian Artery
10. Left Subclavian Vein
11. Left Pulmonary Artery
12. Descending Aorta

The main vessel feeding the right heart is the vena cava. The right atrium also receives venous blood from the coronary sinus, the main venous return of the heart's blood supply.

Approximately 65% of blood volume is normally contained in the venous system. With increased energy demands, blood flow must increase. Table 1.2 outlines blood flow at rest and the changes in blood flow that occurs during strenuous activity. Sympathetic nervous system stimulation is responsible for the majority of the fluctuations in blood flow during exercise, with vasodilation and vasoconstriction occurring simultaneously to increase blood flow to the vital organs (i.e. brain, muscle).

The right ventricle ejects blood through the main branches of the left and right pulmonary arteries to the lungs. The left atrium receives its oxygen-rich blood supply via four main pulmonary veins. The left ventricle ejects blood into the aortic arch to the body. Within the arch, the coronary arteries branch off first followed by three main arteries that branch to the brain (carotids) and the upper thorax (subclavian artery).

Table 2.2 Blood Flow (BF) at Rest and During Exercise

Organ or Tissue	BF at Rest (cardiac output of 5000 ml)	BF with Exercise (volume)
Brain	650 ml	unchanged
Heart	200 ml	up to 3 times more
Muscle	1000 ml	up to 10 times more
Kidney	950 ml	reduced by 40%
Skin	400 ml	up to 4 times more
Abdomen	1200 ml	reduced by 50%
Other	600 ml	reduced by 30%

Note how the heart, skin and muscles receive significantly more blood flow while the abdomen and kidneys experience a reduction in blood supply. The skin's blood supply increases primarily to help release the excess heat yielded by increased energy use. The heart requires increased energy to meet the demands of an increased heart rate and increased stroke volume.

Note that the lion's share of blood volume is delivered to the muscles during exercise. During periods of cardiac ischemia, resting the muscles provide significant reductions to cardiac output demands - and cardiac oxygen demand - thus helping to minimize the extent of the ischemic episode.

Atrial Fibrillation and the Major Vessels

About 1 in 5 people over the age of 50 develop atrial fibrillation, a chaotic quivering of the atria. Blood velocity typically slows along the walls of the atria from the friction between the endocardium and the blood. As long as the atria rhythmically contract, the blood is propelled quickly forward. Without atrial contraction (i.e. atrial fibrillation), blood along the walls can slow significantly. After 48 hours, about 3-5% of people in atrial fibrillation will form a blood clot in the atria.

If this clot is dislodged from the right atrium and floats to the lungs via the pulmonary arteries, a pulmonary emboli results. If a clot develops and moves from the left atrium, the aortic arch is next in line. Of the three main vessels of the arch, two of the three vessels target the brain. As expected, atrial fibrillation is a major risk factor for cerebral vascular accidents (stroke).

Having an understanding of the mechanical structures of the heart helps us make sense of both normal physiology and pathophysiology. Looking at the ramifications of atrial fibrillation is but one example.

Summary

In this chapter we have laid the ground work towards understanding electrocardiograms. The heart is a four-chamber (**2 atria and 2 ventricles**) pump. Its function is to deliver oxygen and nutrient rich blood throughout the body. The heart is often considered two hearts, the right and left heart. The septum is a fibrous barrier that serves as part of the heart's skeleton. The **septum also serves to** separate the right chambers from the left chambers of the heart.

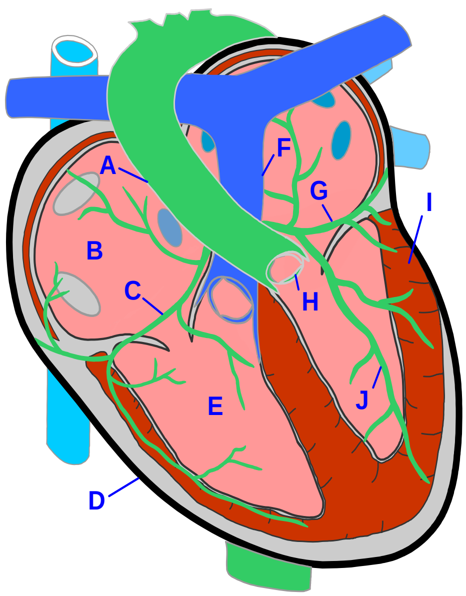
Valves act as gates in the flow of blood. They are located between the atria and ventricles as well as between the ventricles and the major arteries. The heart, being a specialized muscle, requires its own blood supply of oxygen and nutrients. This is provided by **coronary arteries**.

The major vessels of the heart include the vena cava, the pulmonary arteries, the pulmonary veins and the aorta. Together, the heart's mechanical structures synchronize efforts to satisfy the blood and oxygen requirements of the body.

Chapter Quiz

Try this chapter quiz to check whether you are 'anatomically sound'. Good luck.

1. Connect the labels with the appropriate number.



A.	Aortic Valve
B.	Epicardium
C.	Right Atrium
D.	Pulmonary Artery
E.	Right Ventricle
F.	RCA
G.	Aorta
H.	Myocardium
I.	LAD
J.	Circumflex Artery

2. An inferior MI is usually a right ventricular infarction?

True or False

3. A posterior MI can result from an occlusion to the circumflex artery?

True or False

4. The heart is located in the center-left mediastinum between the ____ intercostal space (ICS) and the ____ ICS.

5. Coronary artery perfusion is increased with:

a) growing cardiac energy demands
b) sympathetic neural stimulation
c) widened differences between diastolic pressure and central venous pressure
d) all of the above

Answers: ***1.*** *A. aorta; B. RA; C. RCA; D. epicardium; E. RV; F. PA; G. circumflex; H. aortic valve; I. myocardium; J. LAD* ***2.*** *False* ***3.*** *True* ***4.*** *2nd, 5th* ***5.*** *d)*

6. The atria of the heart (circle all that apply):

a) respond to increased distention by releasing atrial natriuretic peptide to blunt the effects of epinephrine, endothelin and the renin-angiotension cascade
b) pump blood into a nearly empty ventricle
c) are roughly equal to the ventricles in volume and myocardial thickness
d) receive blood from the venous system
e) does not benefit from a valve to prevent atrial backflow during contraction

7. Blood flow to the lungs is roughly equal to the blood flow to the rest of the body.

True or False

8. The AV node and the Bundle of His receive blood from (circle all that apply):

a) the circumflex artery
b) the left anterior descending artery
c) the right coronary artery
d) all of the above

9. The endocardium (circle all that apply):

a) is continuous with the heart valves
b) begins to contract before the epicardium
c) receives blood supply from the distal aspect of the coronary arteries
d) has endocrine functions
e) often experiences ischemia prior to the epicardium
f) provides a smooth surface to facilitate blood flow
g) all of the above

10. While most of the body extracts only a quarter of the oxygen available, the resting heart extracts about (10%, 30%, 50%, 75%) of available oxygen to meet energy demands. This suggests that the heart is very dependent on (coronary artery perfusion, un-extracted oxygen reserves) during periods of high energy demand.

11. Pericarditis is an infection of the protective layers that encase the heart. Resulting inflammation and exudate can cause chest pain and a pericardial effusion.

True or False

12. The heart sounds typically heard with a stethoscope form a S_1 sound during the closure of the (AV valves, semilunar valves) and S_2 during the closure of the (AV valves, semilunar valves).

Answers: ***6.*** *a),d), e)* ***7.*** *True* ***8.*** *a), c)* ***9.*** *all of the above* ***10.*** *75%, coronary artery perfusion* ***11.*** *True* ***12.*** *AV valves, semilunar valves*

13. Tissues that experience increased blood supply during exercise and other high energy demand states include (circle all that apply):

a) heart
b) brain
c) skin
d) muscles
e) kidneys
f) abdomen

14. Atrial fibrillation is associated with increased risk of stroke after a period of (4 hours, 12 hours, 48 hours, 72 hours).

15. Most myocardial infarctions occur to the left ventricle.

True or False

Suggested Readings and Resources

Alexander, W. et al. (2001). Hurst's the Heart. 10th ed. New York: McGraw-Hill

Katz, A.M. (2001). Physiology of the Heart. 3rd ed. London: Lippincott

HeartScape: The Anatomy of the Heart. (2001)
Web: http://www.skillstat.com/heartscapeDemo.html

The Heart: An Online Exploration. Web: http://sln.fi.edu/biosci/heart.html

What's Next?

Understanding the basic structures of the heart is vital to making sense of electrocardiograms. Chapter 3 builds on this knowledge, progressing step by step through the cardiac cycle and the many factors that affect cardiac output.

Answers: ***13.*** *heart, muscles, and skin* ***14.*** *48 hours* ***15.*** *True*