Nuclear Cardiology, Part I: Anatomy and Function of the Normal Heart

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This is the first article of a four-part series on nuclear cardiology. This article introduces and reviews the anatomy and function of the normal heart. Future articles will develop the contribution of nuclear medicine techniques in evaluating myocardial perfusion, function and viability.

This article describes the external and internal features of the heart and its vascularization, conducting system and physiological function. After reading this article, the reader should understand the anatomy and the function of the normal heart.

Key Words: heart; anatomy; physiology; nuclear cardiology


The heart is a thick, muscular, rhythmically contracting organ of the vascular system. It consists of four chambers: a right and a left atrium, and a right and a left ventricle. Left and right chambers are not directly connected but possess one common wall, the septum, which constitutes the medial part of each chamber.

Between the atria and the ventricles, as well as between the ventricles and the great vessels, four valves allow the unidirectional circulation of blood. The total area of the leaflets of each atrioventricular valve is approximately twice that of the respective orifice so that there is considerable overlap of the leaflets in the closed position (1). The valves open and close as a result of changes in blood pressure within the chambers. The pressure in the ventricles rises higher than that in the atria and backward flow of blood is prevented by closure of the valves. The chordae tendineae, which extend from the inferior surface of the valve cusps to the wall of the ventricles, prevent opening upwards. The walls of the ventricles have small muscle projections, called papillary muscles, to which the chordae tendineae are attached.

The cardiac wall, in both the atria and the ventricles, consists of three main layers: the internal layer or endocardium; the intermediate layer or myocardium; and the external layer or epicardium. The internal layer is exposed directly to the blood. The myocardium is composed of specialized muscle tissue, which is found exclusively in the heart.

The pericardium consists of two sacs. The outer sac is of fibrous tissue and the inner is a double layer of serous membrane (2,3). This inner layer is called epicardium. Table 1 shows the general principles of the heart's functioning.

### CARDIAC SIZE, SHAPE AND EXTERNAL FEATURES

The heart is a roughly cone-shaped, hollow muscular organ, with a base, an apex and a series of surfaces and borders. It lies obliquely in the thoracic cavity in the middle mediastinum between the lungs, and approximately one-third of it is located to the right of the midline. Its base is located above and its apex below, and it is surrounded by the following structures (2) (Fig. 1):

- Inferiorly: the central tendon of the diaphragm;
- Superiorly: the great blood vessels (the aorta, superior vena cava, pulmonary artery and pulmonary veins);
- Posteriorly: the oesophagus, trachea, left and right bronchus, descending aorta, inferior vena cava and thoracic vertebrae;
- Laterally: the lungs, the left lung overlapping the left side of the heart; and
- Anteriorly: the sternum, the ribs and the intercostal muscles.

#### TABLE 1

<table>
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<tr>
<th>General Principles of Cardiac Functioning</th>
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<tr>
<td>The right side of the heart pumps deoxygenated (venous) blood.</td>
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<tr>
<td>The left side of the heart pumps oxygenated (arterial) blood.</td>
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<td>The vessels carrying blood to the heart are veins.</td>
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<td>The vessels carrying blood away from the heart are arteries.</td>
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FIGURE 1. The external features of the heart. The adult heart is about 10 cm long and about the size of the owner's fist (2). Adult cardiac weight represents 0.45% of body weight in men and 0.40% in women and is achieved between 17 and 20 yr of age. Reprinted with permission from: Ross JS, Wilson KJW. Foundations of anatomy and physiology, 5th ed. Edinburgh: Churchill Livingstone; 1981: 59; figure 5.6.

CARDIAC CHAMBERS AND INTERNAL FEATURES

Right Heart

The two largest veins of the body, the superior and inferior vena cavae, empty their contents into the right atrium. This blood passes through the tricuspid valve (right atrioventricular valve) into the right ventricle, from which it is pumped into the common pulmonary artery or trunk through the pulmonary valve. The pulmonary trunk divides into a left and a right pulmonary artery. These arteries carry the venous blood to the lungs where the interchange of gases occurs. Carbon dioxide is excreted and oxygen is absorbed (2).

Right Atrium. The right atrium, a roughly quadrangular chamber, lies anterior as well as right of the left atrium, also extending inferior to it (Fig. 2). The right atrial interior presents two main aspects: a posterior (in which the great veins end) and an anterior. The great veins are the superior vena cava (returning blood from the body's upper region), the inferior vena cava (returning blood from the lower body) and the coronary sinus (returning blood from the heart itself) (3).

Right Ventricle. The right ventricle is normally the most anterior cardiac chamber, lying directly beneath the sternum. The right ventricle, which normally contracts against very low resistance, has a crescent-shaped chamber and a thin outer wall, measuring 4–5 mm thick. The interventricular septum separates the right from the left ventricle (4).


Tricuspid Valvular Complex. The valve between the right atrium and right ventricle is made up of three major leaflets of unequal size. The valve opens during the relaxation phase of the ventricle, or diastole, to fill the right ventricle with deoxygenated blood returning from the venous circulation.

Pulmonary Valve. The opening of the pulmonary artery is guarded by a valve known as the pulmonary valve, which has three semilunar cusps. The cusps are called anterior, right and left. This valve prevents the back flow of blood from the pulmonary trunk into the right ventricle when the ventricular muscle relaxes (4,5).

Left Heart

Two pulmonary veins carry the arterial or oxygenated blood out of each lung. The four pulmonary veins empty their contents into the left atrium of the heart. This blood passes through the mitral valve (the left atrioventricular valve) into the left ventricle. From there it is pumped through the aortic valve into the aorta, the major artery of the general circulation (3).

Left Atrium. The left atrium is located superior and posterior to the cardiac chambers and is roughly cuboidal. Its wall is 3 mm thick, slightly more than that of the right atrium. Two pulmonary veins enter posterolaterally on each side. There are no true valves at the junction of the pulmonary veins and the left atrium (6).

Left Ventricle. In contrast to the right ventricle, the construction of the left ventricle is consistent with its role as a powerful muscular pump aimed at sustaining pulsatile flow in high-pressured systemic arteries. Roughly bullet-shaped with the
Blunt or apex directed anteriorly, inferiorly and to the left (7, 8), the left ventricle is approximately an ellipsoidal sphere with thick muscular walls 8–15 mm thick. It is two to three times the thickness of the right ventricular wall. The major portion of its external surface is posterolateral.

**Mitril Valve Complex.** The valve separating the left atrium from the left ventricle is called the left atrioventricular valve, or mitral valve, and is composed of two cusps. It is smaller than the tricuspid orifice. In the left ventricle, the two groups of papillary muscles arise from the junction of the apical and middle third of the ventricular wall. The mechanism of closure is the same as in the tricuspid valve (9, 10).

**Aortic Valve.** The opening of the aorta is guarded by the aortic valve. Although stronger in construction, the aortic valve resembles the pulmonary valve.

**CORONARY ARTERIES**

The specific vascularization of the cardiac muscle is ensured by two principal vessels, the right and left coronary arteries. These carry the arterial, oxygenated blood from the aorta through ever smaller ramifications, branching out over the surface of the heart before ending within the muscle in a fine capillary network. (11, 12) (Fig. 3).

**Right Coronary Artery**

The right coronary artery courses from its origin, in the ascending aorta, into the right anterior atrioventricular groove between the right atrium and the right ventricle. In the groove, it descends almost vertically to the right cardiac border, curving around it into the posterior part of the groove. It divides terminally in two directions. Two or more branches descend in or near the posterior interventricular groove toward the apex of the heart, while another stout branch continues in the left atrioventricular groove (13). The right coronary artery supplies the right atrium, the right ventricle, the posterior part of the interventricular septum and most of the inferior wall of the left ventricle.

**Left Coronary Artery**

The main left coronary artery is usually larger than the right coronary artery and supplies a greater volume of myocardium, namely the left atrium, the left ventricle and the anterior portion of the interventricular septum. After a short trajectory, the main left coronary artery divides into a large branch (the left anterior descending coronary artery or LAD) which runs down the anterior interventricular groove, and a smaller branch (the left circumflex coronary artery or LCX) which courses into the left atrioventricular groove (7).

**Left Anterior Descending Artery.** The LAD appears to be a direct continuation of the main left coronary artery. It gives off major branches in two directions: those which course over the free wall of the left ventricle and those which penetrate and curve posteriorly into the interventricular septum. The artery reaches the apex, terminating there in one-third of specimens, but more often turning round the apex into the posterior interventricular groove, in which it traverses one-third to one-half of its length, to meet the terminal twigs of the corresponding right coronary artery.

**Left Circumflex Artery.** The LCX runs to the left in the atrioventricular groove, going around the heart to the posterior part of the groove. Its branches supply most of the left atrium, the lateral wall and part of the posterior wall of the left ventricle (11, 13, 14). The two significant atrial branches are the one supplying the sinus node in about 45% of human hearts and the left atrial circumflex artery.

**CONDUCTING SYSTEM: COORDINATION OF CARDIAC PUMP FUNCTION**

The heart has an intrinsic system whereby the muscle is stimulated to contract without the need for nerve supply from
the brain (Fig. 4). However, the intrinsic system can be stimulated or depressed by nerve impulses initiated in the brain (2).

**Sinus Node**

The sinus (SA) node, the cardiac pacemaker, is generally considered to initiate excitation of each cardiac cycle. This small mass of specialized cells lies in the wall of the right atrium near the opening of the superior vena cava. The shape of the node is roughly a flattened ellipse.

**Atrioventricular Node**

The atrioventricular (AV) node consists of neuromuscular tissue and is located also on the right side of the heart near the atrioventricular valves. One AV nodal function is triage of atrial signals for transmission to the ventricles. Another function is a delay of approximately 0.04 sec in AV transmission, which occurs at or near the atrionodal junction.

**Atrioventricular Bundle**

This bundle of specialized fibers, called the bundle of His, originates from the AV node and passes downwards in the interventricular septum. It then divides into two branches, one going to each ventricle. Within the myocardium of the ventricles, the branches break up into a network of fine filaments or fibers known as the fibers of Purkinje. The atrioventricular bundle and the Purkinje fibers convey the impulse of contraction from the atrioventricular node to the myocardium of the ventricles.

The impulses of contraction initiated by the sinus node stimulate the myocardium of the atria to contract. This wave of contraction stimulates the atrioventricular node to produce impulses that pass to the apex of the heart through the Purkinje fibers before being transmitted to the ventricular muscle. In this way the ventricular contraction begins at the apex of the heart and blood is forced into the pulmonary artery and the aorta that leave the heart near its base (2).

**PHYSIOLOGICAL FUNCTION OF THE HEART**

The heart behaves as a pulsatile pump, maintaining perfusion of pulmonary and systemic tissues through a series of events known as the cardiac cycle. The cardiac cycle consists of an atrial systole (contraction of the atria), followed by a ventricular systole (contraction of the ventricles) and lastly by a complete cardiac diastole or relaxation of the atria and ventricles.

The superior vena cava and the inferior vena cava pour deoxygenated blood into the right atrium at the same time as the four pulmonary veins pour oxygenated blood into the left atrium. The sinus node emits an impulse of contraction that stimulates the myocardium to contract. The contraction spreads like a wave over both atria, pushing the blood through the atrioventricular valves into the ventricles. Excitation and contraction of the atria are synchronous and terminates before ventricular contraction starts due to an atrioventricular conduction delay. When the wave of contraction reaches the atrioventricular node, it is stimulated to emit an impulse of contraction. The impulse spreads to the ventricular muscle through the atrioventricular bundle and the Purkinje fibers, resulting in a wave of contraction that sweeps upward from the apex of the heart and pushes the blood into the pulmonary artery and the aorta. After contraction of the ventricles, the heart rests for 0.4 sec. This rest period is known as cardiac diastole. Afterwards, the cycle begins again with atrial systole.

The valves of the heart and of the great vessels open and close according to the pressure within the cardiac chambers. At the start of the cardiac cycle, the atrioventricular valves are open. When the ventricles contract, intraventricular pressure gradually increases, and when it rises above atrial pressure the atrioventricular valves close. When the ventricular pressure rises above that in the pulmonary artery and the aorta, the pulmonary and aortic valves open and blood flows into these vessels.

When the ventricles relax and the pressure within the ventricles falls, the reverse process occurs. First the pulmonary and aortic valves close, then the atrioventricular valves open and the cycle begins again. This sequence of opening and closing ensures that the blood flows in only one direction (2).

To ensure adequate contraction of the cardiac muscle, the myocytes, or muscular cells of the heart, transform the nutrients supplied by the coronary arteries into high-energy phosphates. Depending on the oxygen delivery on one hand, and the nutritional status on the other, two main metabolic pathways ensure the production of these high-energy phosphates in the myocytes. The main metabolic chain is very oxygen consuming and oxidizes fatty acids through beta-oxidation. In the fasting state, it provides almost all the energy production of the heart, necessary to generate cardiac contraction. The secondary pathway, which consumes less oxygen but is less energy efficient, uses carbohydrates, especially glucose. In the postprandial state, as the circulating level of carbohydrates is significantly increased, their use is physiologically increased also and 30%-50% of the energy production is obtained from the metabolism of carbohydrates (14).

**REFERENCES**


