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The human heart: structure, function, and clinical significance

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Abstract. The human heart is a remarkable muscular organ responsible for circulating blood throughout the body via two distinct circuits: the pulmonary and systemic circulations. This article provides a comprehensive overview of cardiac anatomy, encompassing the gross structure of the heart, its four chambers and valvular apparatus, the coronary vascular supply, the conduction system, and the histological organization of cardiac muscle. Understanding the structural basis of cardiac function is essential for clinical medicine, as many of the most prevalent and life-threatening conditions — including coronary artery disease, valvular disorders, and arrhythmias — are rooted in anatomical pathology. This review synthesizes classical anatomical knowledge with contemporary clinical relevance to serve as a foundational reference for students, researchers, and healthcare professionals.
Keywords: cardiac anatomy, myocardium, valvular apparatus, coronary circulation, conduction system, pericardium

Аннотация. Человеческое сердце - это замечательный мышечный орган, отвечающий за циркуляцию крови по всему телу по двум различным каналам: легочному и системному кровообращению. В этой статье представлен всесторонний обзор анатомии сердца, охватывающий общую структуру сердца, его четыре камеры и клапанный аппарат, кровоснабжение коронарных сосудов, проводящую систему и гистологическую организацию сердечной мышцы. Понимание структурных основ сердечной деятельности имеет важное значение для клинической медицины, поскольку многие из наиболее распространенных и опасных для жизни состояний, включая ишемическую болезнь сердца, нарушения работы клапанов и аритмии, коренятся в анатомической патологии. В этом обзоре классические анатомические знания объединены с современными клиническими данными, что позволяет использовать его в качестве базового справочника для студентов, исследователей и медицинских работников.
Ключевые слова: анатомия сердца, миокард, клапанный аппарат, коронарное кровообращение, проводящая система, перикард.

Annotatsiya. Yurak faoliyatining strukturaviy asoslarini tushunish klinik tibbiyot uchun juda muhim, chunki eng keng tarqalgan va hayot uchun xavfli bo'lgan ko'plab kasalliklar, jumladan koronar arteriya kasalligi, klapanlarning buzilishi va aritmiyalar anatomik patologiyaga asoslangan., koronar qon tomirlari bilan ta'minlanishi, o'tkazuvchanlik tizimi va yurak mushaklarining gistologik tashkil etilishini o'z ichiga oladi. Yurak faoliyatining strukturaviy asoslarini tushunish klinik tibbiyot uchun juda muhim, chunki eng keng tarqalgan va hayot uchun xavfli bo'lgan ko'plab kasalliklar, jumladan koronar arteriya kasalligi, klapanlarning buzilishi va aritmiyalar anatomik patologiyaga asoslangan. Ushbu sharh klassik anatomik bilimlarni zamonaviy klinik ahamiyatga ega bo'lgan ma'lumotlar bilan sintez qiladi va talabalar, tadqiqotchilar va sog'liqni saqlash sohasi mutaxassislari uchun asosiy ma'lumotnoma bo'lib xizmat qiladi.
Kalit so'zlar: yurak anatomiyasi, miokard, klapan apparati, koronar qon aylanishi, o'tkazuvchanlik tizimi, perikard

1. Introduction

The heart is the central organ of the cardiovascular system, positioned within the mediastinum of the thoracic cavity and enclosed by the pericardial sac. In the average adult, the heart weighs approximately 250–350 grams and measures roughly 12 cm in length, 9 cm in width, and 6 cm in depth. It beats approximately 100,000 times per day, propelling around 5 litres of blood per minute at rest — a feat sustained continuously from the fourth week of embryonic development until death.

Functionally, the heart operates as a dual pump. The right side receives deoxygenated blood from the systemic circulation and propels it to the lungs via the pulmonary circulation, while the left side receives oxygenated blood from the pulmonary veins and distributes it throughout the body via the systemic circulation. Despite this functional division, both sides contract in a coordinated and rhythmic fashion, governed by a specialised intrinsic electrical conduction system.

A thorough understanding of cardiac anatomy underpins clinical reasoning across virtually all medical specialties. Pathological alterations in chamber dimensions, valve morphology, coronary anatomy, and myocardial histology manifest in the most prevalent causes of morbidity and mortality worldwide. This article offers a detailed anatomical account of the human heart, integrating structural descriptions with their physiological and clinical implications.

2. Gross Anatomy and Surface Projections

2.1 Location and Orientation

The heart occupies the middle mediastinum, lying posterior to the sternum and costal cartilages, anterior to the vertebral column (T5–T8), and superior to the diaphragm. Its long axis runs obliquely from the right shoulder toward the left hip. Approximately two-thirds of the cardiac mass lies to the left of the midsternal line. The heart rests upon the central tendon of the diaphragm and is flanked on either side by the lungs, which indent its lateral surfaces to form shallow cardiac impressions.

The surfaces of the heart are classically described as follows:

- Sternocostal (anterior) surface — formed predominantly by the right ventricle
- Diaphragmatic (inferior) surface — composed mainly of the left ventricle and a small portion of the right ventricle
- Left pulmonary (left) surface — formed by the left ventricle and the left auricle
- Right pulmonary (right) surface — formed by the right atrium
- Base (posterior surface) — formed by the left atrium and contributions from the right atrium, receiving the pulmonary veins
- Apex — a blunt, rounded point formed exclusively by the left ventricle, projecting into the left fifth intercostal space at the midclavicular line

2.2 External Landmarks

Several grooves on the external cardiac surface correspond to the internal septa separating the chambers:

- Atrioventricular (coronary) groove — encircles the heart at the junction of the atria and ventricles; contains the coronary arteries, cardiac veins, and coronary sinus
- Anterior interventricular groove — descends on the sternocostal surface and lodges the left anterior descending (LAD) artery and great cardiac vein
- Posterior interventricular groove — runs on the diaphragmatic surface and contains the posterior interventricular artery and middle cardiac vein

3. The Pericardium

The pericardium is a fibroserous sac enclosing the heart and the roots of the great vessels. It is composed of two anatomically and functionally distinct components:

The fibrous pericardium is a tough, inelastic outer layer of dense connective tissue. It is firmly anchored to the central tendon of the diaphragm inferiorly, blends with the adventitia of the great vessels superiorly, and is attached to the posterior surface of the sternum anteriorly via the sternopericardial ligaments. This rigidity serves a critical protective function, preventing overdistension of the cardiac chambers during acute volume overload.

The serous pericardium consists of two continuous layers separated by the pericardial cavity. The parietal layer lines the inner surface of the fibrous pericardium, while the visceral layer (epicardium) is intimately adherent to the myocardium. Between these layers lies a potential space containing 15–50 mL of serous pericardial fluid, which functions as a lubricant, reducing friction during cardiac contraction. Pathological accumulation of fluid in this space — pericardial effusion — can lead to cardiac tamponade, a life-threatening compression of the heart.

Two clinically important recesses are formed by the reflections of serous pericardium: the transverse sinus (posterior to the aorta and pulmonary trunk, anterior to the superior vena cava) and the oblique sinus (a blind-ended recess posterior to the left atrium). The transverse sinus is surgically significant during cardiac surgery as a site for placement of vascular clamps.

4. The Four Cardiac Chambers

4.1 Right Atrium

The right atrium forms the right border of the heart and receives deoxygenated blood from the superior vena cava (SVC), the inferior vena cava (IVC), and the coronary sinus. The interior of the right atrium is divided into two regions by the crista terminalis, a vertical muscular ridge. The posterior smooth-walled region (sinus venarum) is derived from the embryonic sinus venosus, while the anterior trabeculated region is derived from the primitive atrium and is lined by pectinate muscles. The right auricle is a small conical appendage projecting anteriorly from the atrium.

The interatrial septum forms the posteromedial wall of the right atrium. The fossa ovalis, an oval depression in the septum, represents the remnant of the foramen ovale — a fetal communication that allows blood to bypass the non-functional fetal lungs. Failure of this structure to close after birth results in a patent foramen ovale, present in approximately 25% of the adult population.

4.2 Right Ventricle

The right ventricle occupies the majority of the sternocostal surface and is separated from the right atrium by the tricuspid valve. The interior is heavily trabeculated with irregular muscular ridges (trabeculae carneae). The conus arteriosus (infundibulum) is a smooth-walled outflow tract leading to the pulmonary valve and trunk. Three papillary muscles — anterior, posterior, and septal — attach to the free edges of the tricuspid valve leaflets via chordae tendineae, preventing valve eversion during ventricular systole.

The right ventricle generates pressures of approximately 25/5 mmHg (systolic/diastolic) — considerably lower than the left ventricle — reflecting the low-resistance pulmonary vascular bed. Its wall thickness is correspondingly thinner, averaging 3–5 mm compared to 8–15 mm for the left ventricle.

4.3 Left Atrium

The left atrium forms the base (posterior surface) of the heart and receives oxygenated blood from the four pulmonary veins — two superior and two inferior — which enter without valves. The interior is predominantly smooth-walled, with pectinate muscles confined to the left auricle. The left auricle is a finger-like appendage with a narrow neck, and its trabeculated interior predisposes it to thrombus formation in conditions of stasis, particularly atrial fibrillation.

4.4 Left Ventricle

The left ventricle forms the apex and the left (pulmonary) surface of the heart. It is conical in shape and features thick myocardial walls adapted to generate sufficient pressure to drive blood through the high-resistance systemic circulation — generating systolic pressures of approximately 120 mmHg. The interior contains coarse trabeculae carneae and two papillary muscles (anterior and posterior), which support the mitral valve leaflets via chordae tendineae.

The interventricular septum is composed of a thick muscular portion and a thin fibrous membranous portion superiorly near the aortic root. The membranous septum is the most common site of ventricular septal defects (VSDs), the most frequent congenital cardiac anomaly.

5. The Valvular Apparatus

The four cardiac valves ensure unidirectional blood flow through the heart. They can be categorised into two functional groups:

Valve	Type	Location	Leaflets	Pressure (mmHg)
Tricuspid	Atrioventricular	Right AV junction	3	~25/5
Pulmonary	Semilunar	RVOT / pulmonary trunk	3	~25/10
Mitral (Bicuspid)	Atrioventricular	Left AV junction	2	~120/8
Aortic	Semilunar	LVOT / aortic root	3	~120/80

The atrioventricular valves (tricuspid and mitral) open during diastole and close during systole, preventing regurgitation of blood into the atria. The semilunar valves (pulmonary and aortic) open during systole and close during diastole, preventing backflow into the ventricles. Stenosis or incompetence of any of these valves — whether congenital or acquired (e.g., rheumatic fever, infective endocarditis) — produces characteristic murmurs and haemodynamic consequences with precise anatomical correlates.

6. Coronary Circulation

6.1 Coronary Arteries

The coronary arteries are the first branches of the aorta, arising from the aortic sinuses (sinuses of Valsalva) immediately above the aortic valve cusps. They supply the myocardium during diastole, when ventricular pressure falls below aortic pressure and blood flows into the coronary ostia.

The left coronary artery (LCA) arises from the left aortic sinus and divides within centimetres into two major branches: the left anterior descending (LAD) artery, which descends in the anterior interventricular groove to supply the anterior left ventricle, anterior interventricular septum, and the cardiac apex; and the left circumflex (LCx) artery, which courses in the left atrioventricular groove and supplies the lateral and posterior walls of the left ventricle and the left atrium. The LAD is the most clinically significant coronary artery and is colloquially termed the 'widow maker' because its occlusion leads to extensive anterior myocardial infarction.

The right coronary artery (RCA) arises from the right aortic sinus, traverses the right atrioventricular groove, and in approximately 70% of individuals (right-dominant pattern) gives rise to the posterior descending artery (PDA), supplying the inferior left ventricle, the posterior third of the interventricular septum, and critically the sinoatrial (SA) and atrioventricular (AV) nodes. Left dominance (LCx gives rise to the PDA) occurs in approximately 10% of individuals, with co-dominance in the remaining 20%.

6.2 Cardiac Veins and Coronary Sinus

Venous drainage of the myocardium is achieved primarily via the coronary sinus, which lies in the posterior atrioventricular groove and drains into the right atrium. Its major tributaries include the great cardiac vein (accompanying the LAD), the middle cardiac vein (accompanying the PDA), and the small cardiac vein (accompanying the RCA). Thebesian veins drain directly into the cardiac chambers, particularly the right heart, accounting for a small component of physiological shunting.

7. The Cardiac Conduction System

The heart possesses an intrinsic electrical conduction system composed of specialised myocytes capable of spontaneous depolarisation (automaticity). This system coordinates the sequential contraction of the atria and ventricles to ensure haemodynamically efficient pumping.

The sinoatrial (SA) node, located in the superior right atrium near the junction with the SVC, is the dominant pacemaker of the heart, generating impulses at 60–100 beats per minute. Electrical depolarisation spreads through atrial myocardium to the atrioventricular (AV) node, situated at the apex of the triangle of Koch in the right atrium, near the opening of the coronary sinus. The AV node introduces a critical physiological delay (approximately 120 ms), allowing atrial contraction to complete before ventricular depolarisation begins.

From the AV node, the impulse travels along the bundle of His (atrioventricular bundle), the only electrical connection between atria and ventricles in the normal heart, into the membranous interventricular septum, where it divides into the right and left bundle branches. The left bundle branch subdivides into anterior and posterior fascicles. These fibres terminate in the subendocardial Purkinje

network, which rapidly distributes the impulse across the ventricular myocardium, producing synchronised contraction from apex to base.

Pathological disruption of the conduction system produces clinically important arrhythmias. AV nodal block may present as heart block of varying degrees. Bundle branch blocks alter the morphology of the QRS complex on the electrocardiogram and can indicate underlying ischaemia, cardiomyopathy, or structural disease. SA node dysfunction manifests as sick sinus syndrome, often requiring permanent pacemaker implantation.

8. Histology of Cardiac Muscle

Cardiac muscle (myocardium) is composed of cardiomyocytes — specialised, terminally differentiated striated muscle cells with unique structural adaptations for continuous rhythmic contraction. Each cardiomyocyte is typically cylindrical, 85–100 μm in length and 15–25 μm in diameter, with one or two centrally placed nuclei.

Cardiomyocytes are arranged in branching, anastomosing networks and are connected end-to-end at specialised junctions called intercalated discs. These transverse structures contain three components: fascia adherens (mechanical adhesion), desmosomes (structural integrity), and gap junctions (electrical coupling via connexin proteins). Gap junctions allow the rapid propagation of action potentials between adjacent cells, enabling the myocardium to function as an electrical syncytium.

The contractile apparatus of cardiomyocytes consists of myofibrils composed of sarcomeres — the fundamental units of contraction. Each sarcomere contains interdigitating thick filaments (myosin) and thin filaments (actin), along with regulatory proteins troponin and tropomyosin. The troponin complex (troponin I, T, and C) is of particular clinical significance: cardiac-specific isoforms of troponin I and troponin T are released into the bloodstream following cardiomyocyte injury and serve as the gold-standard biomarkers for myocardial infarction.

Unlike skeletal muscle, the myocardium is highly resistant to fatigue, owing to its dense mitochondrial content (25–35% of cell volume) and its reliance on aerobic metabolism, primarily utilising fatty acids (60–70% of energy substrates at rest) and glucose. The myocardium has minimal anaerobic capacity, rendering it exquisitely sensitive to ischaemia — a fact that underlies the irreversible cell death occurring within 20–40 minutes of coronary artery occlusion.

9. Clinical Significance

An understanding of cardiac anatomy is indispensable to the diagnosis and management of cardiovascular disease, which remains the leading cause of mortality worldwide. Several major categories of disease are directly anatomically grounded:

Coronary artery disease (CAD) results from atherosclerotic plaque formation within the coronary arteries, reducing myocardial perfusion. Acute plaque rupture triggers thrombus formation and myocardial infarction, the extent and territory of which are determined by the anatomy of the affected vessel.

Valvular heart disease encompasses stenosis (obstructed opening) or regurgitation (incomplete closure) of any cardiac valve, producing characteristic haemodynamic consequences and auscultatory findings. Echocardiography provides non-invasive anatomical assessment of valve morphology and function.

Congenital heart disease encompasses a wide spectrum of anatomical malformations arising from defective embryological development, including septal defects, valve anomalies, and complex lesions such as tetralogy of Fallot. The anatomical complexity of these conditions necessitates specialised surgical and interventional approaches.

Heart failure, characterised by impaired cardiac output relative to physiological demands, may arise from systolic dysfunction (reduced contractility), diastolic dysfunction (impaired relaxation and filling), or both — each with distinct anatomical and histological correlates.

10. Conclusion

The human heart is an anatomically intricate organ whose precise structural organisation directly underlies its remarkable functional capacity. From the arrangement of its four chambers and valvular apparatus to the microscopic architecture of its cardiomyocytes, every structural element serves a

defined physiological role. The coronary vasculature ensures uninterrupted metabolic support for the ceaseless work of the myocardium, while the conduction system coordinates the electrical events that govern its rhythm.

A comprehensive knowledge of cardiac anatomy constitutes the foundation upon which clinical cardiology is built. Whether interpreting an electrocardiogram, performing a cardiac catheterisation, conducting an echocardiographic examination, or undertaking cardiac surgery, the clinician must possess a thorough and precise anatomical framework. As imaging technologies continue to advance and minimally invasive cardiac interventions proliferate, the importance of three-dimensional anatomical reasoning in clinical practice will only intensify.

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