Heart and Pericardium

The heart is a muscular pump, or in actuality two pumps, that are responsible for circulating blood through the pulmonary circulation of the lungs and the systemic circulation of the body. The pericardium serves to protect the heart and to hold it in position while concurrently creating a frictionless environment for the contraction/relaxation cycles of the heart.

Pericardium

Fibrous Pericardium

1) dense, outer connective tissue layer that protects the heart and holds it in position
2) tethered to the central tendon of the diaphragm and posterior side of sternum
3) continuous with the outer adventitial layer of the neighboring great vessels

Serous Pericardium

1) a serous membrane, i.e. a mesothelium (mesodermally-derived simple squamous epithelium) sitting on a thin framework of loose connective tissue
2) a continuous, uninterrupted membrane that is subdivided into two parts, visceral and parietal layers of the serous pericardium
3) parietal layer – immediately deep to the fibrous pericardium
4) visceral layer (syn. epicardium) – covers the outer surface of the heart
5) pericardial cavity – narrow space between parietal and visceral layers (the heart is surrounded by the pericardial cavity, it is not in the pericardial cavity)
6) pericardial fluid – fluid in the pericardial cavity
   a) derived from the interstitial fluid of the pericardium; continuously traverses the serous pericardium and is reabsorbed into the lymphatics underlying the serous pericardium
   b) a lubricant that creates a frictionless environment
7) nerve supply
   a) parietal part of serous pericardium and fibrous pericardium – sensory innervation from phrenic nerves (C3 – C5)
   b) epicardium – autonomic innervation from the underlying heart

Clinical Notes: 1) Pericardial effusion - an abnormal accumulation of fluid in the pericardial cavity which may or may not cause a significant increase in the pressure, called intrapericardial pressure, within the pericardial cavity. Has the potential to compromise cardiac activity by compressing the heart, reflecting the limited potential of the pericardial cavity to expand outward due to the presence of the noncompliant fibrous pericardium while capable of more readily expanding inward upon the underlying and more compliant heart. Pericardial effusion typically results from a change in the normal equilibrium between the production and re-absorption of pericardial fluid or a breach in the structural integrity of the pericardium that allows fluid to enter the pericardial cavity. 2) Pericardial tamponade (syn. pericardial compression or cardiac tamponade) - a term used to describe a pericardial effusion with sufficient pressure to adversely effect heart function. 3) Etiologies - the causes of pericardial effusion or pericardial tamponade are many with inflammation of the pericardium (pericarditis) a leading cause, the inflammation being a response to pathogenic microorganisms (infectious pericarditis) that spread from contiguous structures, e.g. lungs and pleural cavities, or that have seeded the pericardium from a systemic infection (septicemia). Pericardial effusion or tamponade may also result from the obstruction of lymphatic flow from the heart and pericardium due to malignant diseases (e.g. lung cancer) that block lymph nodes of the mediastinum. Trauma may result in a rapid filling of the pericardial cavity with fluid, such as an accumulation of blood following a penetrating wound (e.g. gunshot, knife wound) of the heart. 4) Pericardiocentesis – a surgical technique that introduces a needle or indwelling catheter into the pericardial cavity for the purpose of draining the fluid of a pericardial effusion or tamponade.

Anatomy of the Heart

Pattern of Blood Flow

1) terms arteries and veins denote direction of blood flow relative to the heart and not the oxygen state of the blood
2) the four cardiac valves are positioned at the entrances to and the exits from the two ventricles
3) pattern of blood flow (a to h) through the cardiac chambers and neighboring great vessels:
   a) superior vena cava (SVC) and inferior vena cava (IVC)
   b) right atrium (RA)
   c) right ventricle (RV)
   d) pulmonary trunk and pulmonary arteries
   e) pulmonary veins
   f) left atrium (LA)
   g) left ventricle (LV)
   h) ascending aorta

Arrangement of the Cardiac Chambers

1) two atria side-by-side at one end
2) two ventricles side-by-side at the other end
3) tip of the long axis of the heart points to the left, anterior, and inferior
4) heart is two pumps
   a) RA-RV pump (i.e. the “right side” of the heart) for the pulmonary circulation
   b) LA-LV pump (i.e. the “left side” of the heart) for the systemic circulation

External Surfaces

1) sternocostal (anterior) surface – RA, RV, and LV
2) apex – part of the LV
3) diaphragmatic surface – RV and LV
4) posterior surface (syn. base) – mostly LA, some RA

Borders

1) right border – the extreme of the right side formed by the RA
2) left border – the extreme of the left side formed by the LV, including apex, and some LA via the left auricle
3) inferior border – the sharp edge of transition between the sternocostal and diaphragmatic surfaces of the RV; not evident in a PA chest film due to underlying diaphragm and liver

Cardiac Valves

1) general features
   a) cusps (syn. leaflets) - connective tissue core covered with endothelium
   b) prevent retrograde (backward) flow of blood (regurgitation)
   c) guard the orifices into and out of the two ventricles
   d) open and close based solely on pressure changes within the cardiac chambers
2) two types
   a) atrioventricular valves – tricuspid and mitral (bicuspid)
      i) broad, sheet-like cusps
      ii) chordae tendineae
      iii) papillary muscles
      iv) positioned at the large orifices that lead from the atria into the ventricles
   b) semilunar – aortic and pulmonary
      i) pocket-like cusps
      ii) sinus – space behind a cusp

iii) positioned at the orifices of the large blood vessels that lead out of the ventricles

Chamber Anatomy

1) Right atrium
   a) right auricle – "ear" like appendage
   b) openings of the SVC, IVC, and coronary sinus
   c) crista terminalis – a vertical ridge of cardiac muscle
   d) pectinate muscles – "comb-like" elevations of the myocardium on the anterior wall
   e) interatrial septum – smooth posterior wall
   f) fossa ovalis (syn. oval fossa) – "thumb print" like depression on the interatrial septum; is the now closed foramen ovale (syn. oval foramen) of the embryo
   g) right atrioventricular orifice
2) Right ventricle
   a) tricuspid valve - 3 cusps with chordae tendineae and papillary muscles
   b) trabeculae carnae – irregular surface elevations of the myocardium
      i) moderator band (septomarginal band) – a prominent trabeculae carnae containing the right branch of the AV bundle
   c) interventricular septum – has a connective tissue "membranous part" and a cardiac muscle "muscular part"
   d) infundibulum – smooth outflow region
   e) pulmonary orifice and pulmonary valve
3) Left atrium
   a) left auricle with pectinate muscles
   b) interatrial septum
   c) left atrioventricular orifice
4) Left ventricle
   a) mitral valve - 2 cusps with chordae tendineae and papillary muscles
   b) trabeculae carnae
   c) interventricular septum
   d) aortic vestibule – smooth outflow region
   e) aortic orifice and aortic valve

Clinical Notes: 1) Atrial septal defects (ASD) – congenital malformations of the interatrial septum; the most common is an incomplete closure of the oval foramen that allows oxygenated blood to pass from the LA into the RA. 2) Ventricular septal defects (VSD) - congenital malformations of the interventricular septum, usually in the membranous (connective tissue) part of the septum near the outflow regions of the chambers; results in a LV to RV shunt of blood. 3) Mitral regurgitation – the abnormal ejection of blood from the left ventricle into the left atrium during ventricular contraction due to a defective mitral valve. Reflects an abnormality in any component of the mitral valve, e.g. papillary muscles, cusps, chordae tendineae, and/or the chamber walls that support these structures. 4) Mitral valve prolapse – movement of a cusp(s) of the mitral valve into the lumen of the left atrium during left ventricular contraction, resulting in mitral regurgitation; affects about 2.5% of men and 5% of women in the U.S.. 5) Aortic stenosis – a narrowing (stenosis) of the left ventricular outflow tract that results in a reduction in the amount of blood ejected from the left ventricle during ventricular contraction. Valvular aortic stenosis refers to a defect in the aortic valve itself, such as in degenerative (senile) calcific aortic stenosis where the cusps degenerate and calcify with age as a result of normal mechanical wear and tear or congenital bicuspid aortic stenosis where the aortic valve has only two cusps rather than three. Subvalvular aortic stenosis (a narrowing below the valve) is often the result of a congenital fibromuscular membrane positioned near the top of the aortic vestibule; supravalvular aortic stenosis (a narrowing above the valve) is typically the result of a congenital coarctation (stricture) of the ascending aorta.

Conducting System of the Heart

Fibrous (Cardiac) Skeleton

1) the connective tissue framework of the heart
2) includes four "fibrous rings" (syn. annulus fibrosus) that surround the four valve-protected orifices of the heart, i.e. aortic, pulmonary, left and right atrioventricular orifices
   a) provide rigidity to the orifices
   b) are continuous with the connective tissue core of the cardiac valves and as such attach the cusps to the orifices
3) continuous with the membranous part of the interventricular septum
4) structurally separates the cardiac muscle fibers of the two atria from the cardiac muscle fibers of the two ventricles (remember – connective tissue cannot conduct a contraction impulse as can cardiac muscle)

Terminology

1) Automaticity – the initiation of a contraction impulse as a result of spontaneous depolarization
2) Conduction – the propagation of a contraction impulse along cardiac muscle fibers; facilitated by the large number and size of gap junctions between cardiac muscle fibers

Components of the Conducting System

1) Sinu-atrial (SA) node
   a) located in the wall of the RA near the top of the crista terminalis
   b) the pacemaker, i.e. the site of normal automaticity based on the fact that its cardiac muscle fibers have the lowest threshold for spontaneous depolarization.
2) Atrioventricular (AV) node
   a) located in the wall of the RA near the opening of the coronary sinus
   b) slows down conduction, ensuring that the atria contract prior to the ventricles
3) AV bundle (bundle of His)
   a) begins at the AV node and then pierces the fibrous skeleton that structurally separates the cardiac muscle fibers of the two atria from the cardiac muscle fibers of the two ventricles
   b) descends the interventricular septum and divides into left and right bundles
   c) function - conducts the contraction impulse from the atria to the ventricles
4) Purkinje fibers
   a) very large, specialized cardiac muscle fibers contained within the AV bundle
   b) have a very rapid conduction rate and unite via gap junctions with the typical cardiac muscle fibers of the two ventricles; the union occurs near the apical end of the heart

Clinical Note: Wolff-Parkinson-White (WPW) Syndrome – a cardiac condition due to the presence of one or more accessory muscular connections (called accessory AV connections or accessory AV pathways) between the two atria and the two ventricles that are capable of conduction. WPW syndrome patients also have a normal AV bundle and thus they have at least two routes for conducting a contraction impulse from the atria to the ventricles. An accessory AV connection does not have an AV node associated with it and thus there is no delay in its conduction. The contraction waves of the normal AV bundle and that of an accessory AV connection fuse in the ventricles. Treatment – divide the accessory AV pathway(s), whose anatomical positions vary, by either open heart surgery or radiofrequency catheter ablation.

Cardiac Cycle

Terminology

1) clinically, but not physiologically, the terms diastole and systole relate only to the state of activity of the cardiac ventricles.

2) diastole – the period of ventricular relaxation
3) systole – the period of ventricular contraction

A Turn of the Cardiac Cycle (in sequence from item 1 to 3)

1) Diastole I
   a) Atria are relaxed
   b) Ventricles are relaxed
   c) AV valves are open and as such blood flows from the atria into the ventricles
      i) initially opened when the ventricles first relaxed and the pressures within the atria exceeded those within the ventricles
   d) Semilunar valves are closed
      i) initially closed when the ventricles first relaxed and the blood within the pulmonary trunk and aorta began to flow backwards due to the pressure gradient
2) Diastole II
   a) Atria contract, pumping additional blood into the ventricles
   b) Ventricles remain relaxed
   c) AV valves remain open
   d) Semilunar valves remain closed
3) Systole
   a) Atria relax
   b) Ventricles contract and the increased pressure in the chambers ejects blood from the ventricular lumens
   c) AV valves close due to the pressure (force) of the moving blood
   d) Semilunar valves open due to the pressure (force) of the moving blood

Clinical Notes: 1) Tachycardia - an abnormally rapid heart rate. 2) Bradycardia - an atypically slow heart rate. 3) Arrhythmia – an abnormal rhythm in the cardiac cycle that may include abnormalities in the rate, regularity, site of impulse origination, and/or the sequence of activation of chambers. Arrhythmias are broadly divided into abnormalities of automaticity, conduction, or a combination of both. An example of an abnormality in automaticity would be an "ectopic pacemaker" in which some area of cardiac muscle other than the SA node gains control of the atrial or ventricular rhythm, potentially placing the contractions of the atria and ventricles out of sequence. An example of an abnormality in conduction (in this example called a conduction delay) would be destruction of a portion of the conducting system of the heart, such as the right branch of the AV bundle following a heart attack that results in the death of the associated myocardium. In this example conduction to the LV is normal (left branch of the AV bundle is intact) but conduction to the RV is delayed because its contraction impulse must now first travel through the typical cardiac muscle fibers of the LV before reaching those of the RV; this results in LV contraction occurring slightly ahead of RV contraction. 4) Atrial fibrillation - an atrial arrhythmia in which small areas of the atrial myocardium contract in a rapid and randomized manner, causing a complete disorganization of atrial contraction and a total loss of effective pumping. 5) Ventricular fibrillation – ventricular arrhythmia in which small areas of the ventricular myocardium contract in a rapid and randomized manner, causing a complete disorganization of ventricular contraction and a total loss of effective pumping – a catastrophic event characterized by a loss of pulse and blood pressure.

Heart Sounds

1) normal heart sounds are due to the closure of the cardiac valves
2) first heart sound (designated S1)
   a) the near simultaneous closure of the mitral and tricuspid valves, their individual sounds designated M1 and T1 respectively
   b) there is a 20 to 30 millisecond difference in the time of closure between the tricuspid and mitral valves; when the sounds of M1 and T1 can be individually distinguished it is referred to as a "split' of S1
3) second heart sound (S2)

a) the near simultaneous closure of the aortic and pulmonary valves, their individual sounds designated A1 and P1 respectively
b) splitting of S2 is best accomplished physiologically during variations in the respiratory cycle; a split is best heard near the end of deep inspiration

Clinical Note: Heart murmurs – abnormal heart sounds due to a variety of conditions including valvular diseases (e.g. mitral valve prolapse), non-valvular abnormalities affecting blood flow (e.g. subvalvular aortic stenosis, septal defects), and diseases of the pericardium (e.g. pericarditis often presents with an abnormal sound generated in the pericardium called a "pericardial friction rub").

Neurovascular Supply of the Heart

Coronary Circulation

1) General information
   a) two coronary arteries, right and left, originate from the ascending aorta behind different cusps of the aortic valve.
   b) the largest coronary arteries and cardiac veins reside within grooves or sulci on the external surface of the heart and are referred to as "epicardial" coronary vessels.
   c) variations in the anatomical pattern of the coronary arteries is common.
2) Right coronary artery
   a) descends the sternocostal surface in the coronary (atrioventricular) groove – sends branches to the RV and RA
   b) notable branches
      i) SA nodal artery
      ii) AV nodal artery
      iii) posterior interventricular artery – traverses the posterior interventricular sulcus on the diaphragmatic surface; sends branches to the RV and LV
3) Left coronary artery
   a) very short, quickly divides into
      i) anterior interventricular artery (commonly referred to as the LAD [left anterior descending] by clinicians) – descends the anterior interventricular sulcus; sends branches to the RV and LV
         (1) notable branches – branches of the LAD are the major source of blood to the interventricular septum, including the enclosed AV bundle
      ii) circumflex artery – descends the coronary (atrioventricular) groove on the posterior side of the heart; sends branches to the LA and LV
4) Cardiac veins – venous return of the coronary arteries
   a) coronary sinus – final common pathway; empties into the lumen of the RA

Clinical Note: 1) Ischemia – a lack of oxygen. 2) Coronary artery disease (ischemic heart disease) – characterized by an inadequate arterial blood supply to the myocardium of the heart. The most common cause of coronary artery disease is atherosclerosis (G. sklerosis, hardness) in which lipid deposits accumulate on and within the walls of coronary arteries, resulting in a narrowing of the arterial lumen which in turn causes a reduction in the amount of blood delivered to the myocardium. 2) Acute myocardial infarction (MI) – the sudden occlusion of a narrowed coronary artery (e.g. following thrombus formation at the site of a ruptured atherosclerotic plaque) that results in the eventual necrosis (morphological features indicative of cell death) of the affected myocardium. 3) Left ventricular hypertrophy – physical enlargement of the left ventricle in an effort to compensate for reduced left ventricular cardiac output (e.g. that caused by aortic stenosis or a ventricular septal defect). The left ventricle enlarges to a point that it outgrows the ability of the coronary arteries to supply its metabolic needs; an example of ischemic heart disease not caused by atherosclerosis. 4) Angina (syn. angina pectoris) – the major symptom of chronic ischemic heart disease; a cardiac pain typically described as a "squeezing" or "crushing" pain behind the sternum. Angina reflects a transient reduction in blood flow to the heart that subsides after a few minutes of rest or with medication (e.g.

nitroglycerin) that dilates the coronary arteries. Angina is usually precipitated by exercise or emotional stress.

Innervation of the Heart

1) Cardiac plexus
   a) a network of autonomic nerve fibers near the bifurcation of the trachea and the right pulmonary artery
   b) contains motor and sensory fibers that course to the heart along the great vessels
2) Parasympathetic nerve fibers - derived from the vagus nerves (CN X)
   a) efferents - decrease heart rate via the SA node
   b) afferents
      i) assess blood pressure via baroreceptors in the walls of the great vessels
      ii) assess the oxygen and carbon dioxide concentrations of aortic blood via chemoreceptors in the walls of the ascending aorta
3) Sympathetic nerve fibers - postganglionic cell bodies in cervical and upper thoracic ganglia of the sympathetic trunks
   a) efferents
      i) increase heart rate via the SA node
      ii) increase the strength of contraction of ventricular cardiac muscle fibers
      iii) cause vasodilation of coronary arteries
   b) afferents - conduct pain associated with ischemia

Surface Anatomy of the Heart

Palpation and auscultation of the heart are diagnostic procedures performed during physical examination of the thorax. One should be able to visualize the underlying cardiovascular anatomy projected onto the anterior chest wall.

1) precordium – clinical term used to refer to the anterior chest wall that overlies the heart.
2) the diaphragm rises slightly in the supine (recumbent) position due to pressure from abdominal organs; as the diaphragm rises so does the heart
3) typical surface projection of the heart based on an average sized adult in the anatomical position during quiet respiration
   b) approximately one-third of the heart resides to the right of the midsternal line, two-thirds to the left
   c) borders
      i) inferior border - lies at the level of the xiphoid-costal junction
      ii) right border – formed by the right atrium; lies slightly lateral to the right side of the body of the sternum; upper limit around the level of the right 3rd costal cartilage; superior and inferior venae cava at its upper and lower extremes
      iii) left border – formed mostly by left ventricle but a small part by auricle of left atrium; lies significantly lateral to the left side of the body of the sternum, descending laterally from near the level of the sternal angle to the left ventricular area (see below)
   d) atria
      i) right atrium - not usually identifiable by palpation or auscultation in a physical exam
      ii) left atrium - comprises what anatomists refer to as the base of the heart; is the deepest (posterior) part and cannot be directly examined in a routine physical examination
         (1) clinicians use the term "base of the heart" to refer not to the left atrium but to the left and right 2nd intercostal spaces close to the sternum (see cardiac valves below).

e) ventricles
  i) right ventricle
    (1) makes up much of the sternocostal (anterior) surface of the heart, lies behind the body of the sternum and notably extends to the left of the sternum
    (2) “right ventricular area” - 3rd through 5th intercostal spaces along the left sternal border where the right ventricular impulse (beat) may be palpable and the chamber is auscultated.
  ii) left ventricle
    (1) “left ventricular area” - region of the apex of the heart, typically in the 4th or 5th intercostal space about 7 to 9 cm from the midsternal line (which positions it just medial to the midclavicular line)
      (a) here one *may* visually observe the apical impulse (syn. cardiac impulse or apical beat) which is the pulsation of the left ventricle in the early systolic phase that briefly contacts the anterior chest wall. Its visibility and palpation can be obscured by obesity or a very muscular chest wall.
      (b) an apical impulse lateral to the midclavicular line may suggest cardiac enlargement or displacement.

4) cardiac valves
  a) grouped closely together behind the sternum
    i) in order to distinguish the sounds of individual valves, auscultation is performed at positions as far apart as possible. Since the sounds are carried by the blood, they are best heard superficial to the chamber or vessels through which the blood has recently passed.
  b) tricuspid valve **-** best heard over the 4th and 5th left intercostal spaces close to the sternum (right ventricular area).
  c) mitral valve - best heard over the apex of the heart (left ventricular area)
  d) pulmonary valve - best heard in the 2nd intercostal space just to the left of the sternum (the clinician's "base of the heart" and referred to as “base left”).
  e) aortic valve – best heard over the 2nd intercostal space immediately to the right of the sternum (clinician's "base of the heart" and referred to as “base right”).
  f) important to appreciate that there are significant areas of overlap on the surface of the chest wall where multiple heart sounds can be heard

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