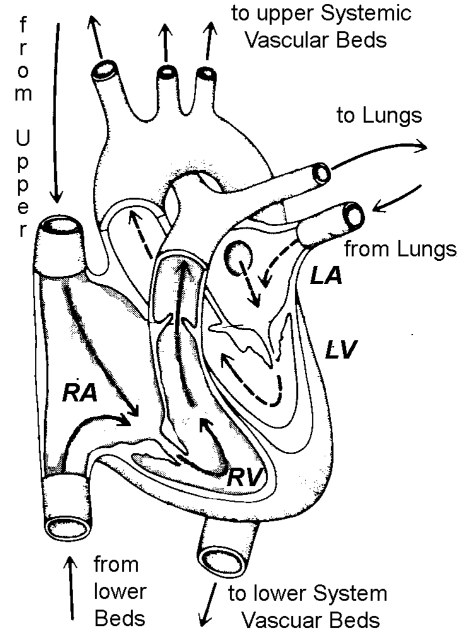
# HEART AS A PUMP

## A. Functional Anatomy of the Heart

1. Two pumps, arranged in series

    a. <u>right heart</u>: receives blood from the systemic circulation (via the great veins and vena cava) and pumps blood into the pulmonary circulation (via the pulmonary arteries)

    b. <u>left heart</u>: receives blood from the pulmonary circulation (via the pulmonary veins) and pumps blood into the systemic circulation (via the aorta)



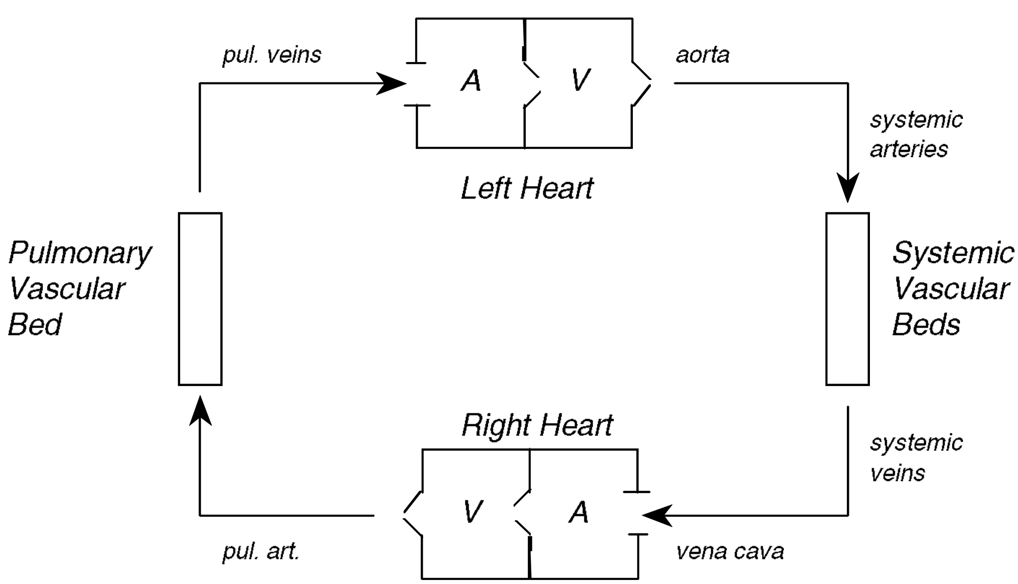

2. Chambers: each side has two chambers

    a. <u>atrium</u>: receives blood from the veins and ejects blood into the ventricle through an A-V (atrio-ventricular) valve

    b. <u>ventricle</u>: receives blood from the atrium and ejects blood into the arterial system through a semilunar valve (ventricles responsible for most of the pumping action of the heart)

3. Valves

| | AV | Semilunar |
|---|---|---|
| right | **tricuspid** | **pulmonic** |
| left | **mitral** | **aortic** |
| | broad<br>low resistance | smaller<br>resist high back pressure |

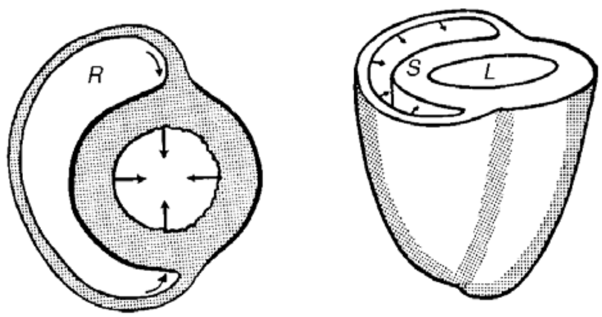



Note: The left and right sides of the heart must pump exactly the same volume of blood when averaged over a period of time

HEART AS A PUMP (continued)

B. Imparting Energy to the Blood

1. Mechanism: longitudinal shortening of myocardial fibers compresses blood in the chamber, raising pressure and causing ejection




R = right ventricle (thin free wall)
L = left ventricle (thick walls)
S = intraventricular septum

C. Valve and Papillary Muscle Function

1. Role of the valves

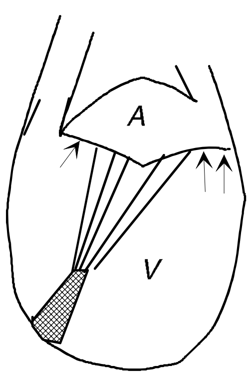
a. impart a direction to the circulation by closing when downstream pressure exceeds upstream pressure, thus preventing backward regurgitation

Note: a valve that permits regurgitation is termed <u>incompetent</u> or <u>insufficient</u>

b. present a low resistance to forward flow by opening when upstream pressure exceeds downstream

Note: a valve that cannot open completely and therefore presents an appreciable resistance to forward flow is termed <u>stenotic</u>

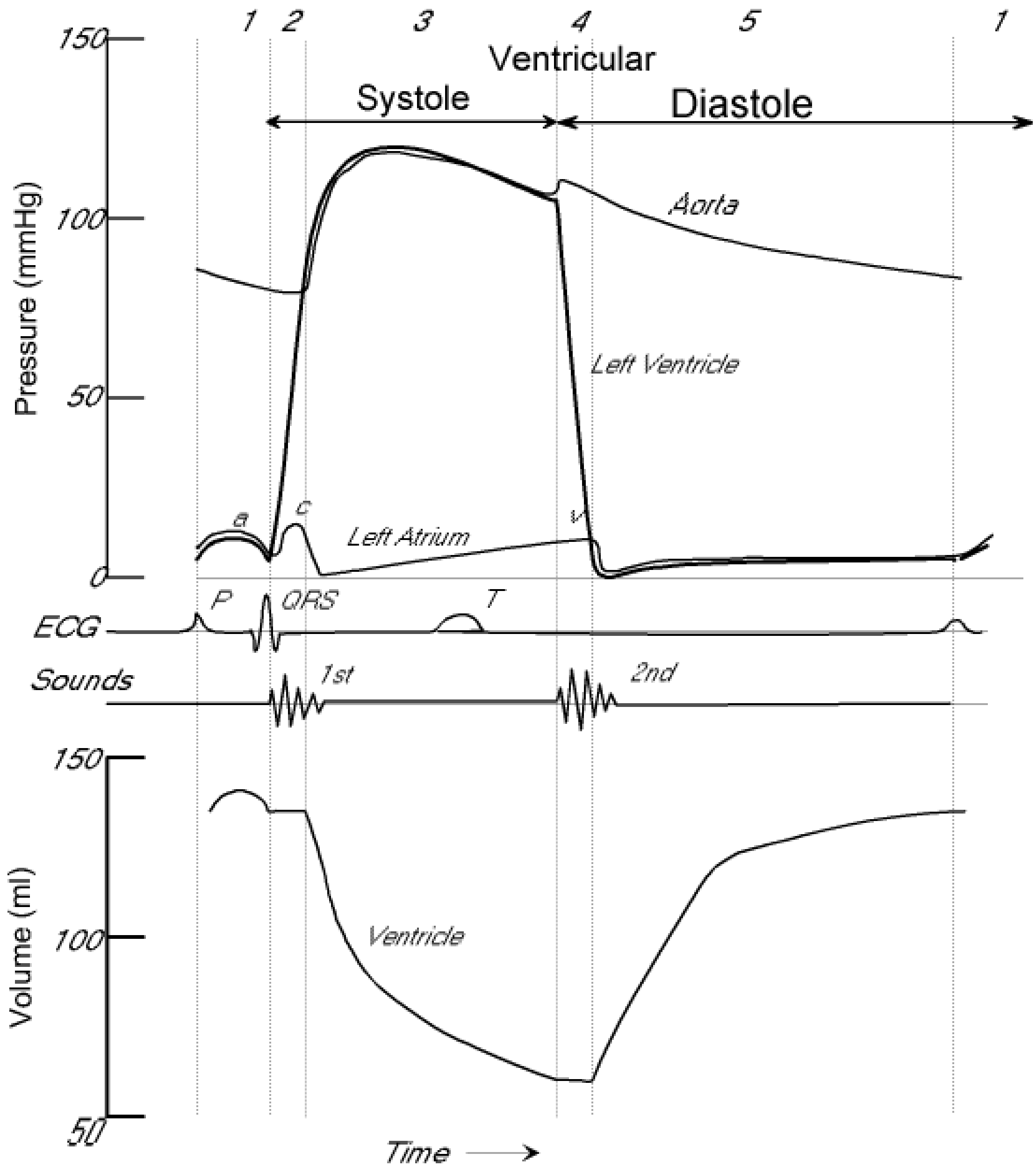
2. Role of the papillary muscles: Aid A-V valves to resist high pressure (particularly the mitral valve)




Note <u>prolapse</u> of the mitral valve upon papillary muscle injury, possibly causing the mitral valve to become incompetent

CARDIAC CYCLE: PRESSURE AND VOLUME RELATIONS

A. Left Heart




| | ***Atria*** | ***Ventricles*** |
|---|---|---|
| 1. Atrial Contraction | Systole | Diastole |
| 2. Isovolumetric Contraction | Diastole | Systole |
| 3. Ventricular Ejection | " | " |
| 4. Isovolumetric Relaxation | " | Diastole |
| 5. Ventricular Filling | " | " |

***Systole*** = active contraction
***Diastole*** = relaxation

Note: the highest pressure at a particular location (artery, vein, atrium, ventricle) is called its ***systolic pressure***; the lowest pressure at the location is called its ***diastolic pressure***

CARDIAC CYCLE (continued)

Note: The volume in the ventricle just before systole begins is called the ***end diastolic volume*** (EDV); the volume left in the ventricle at the end of systole is called the ***end systolic volum***e (ESV)

B. Phases

1. Atrial contraction

   a. preceded by P wave (atrial excitation)

   b. pressure rise in atrium, small, transient (venous "a" wave)

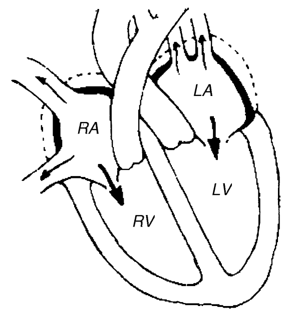
   c. increase ventricular volume, small, transient at rest

   d. mitral and tricuspid valves open at the beginning; may be closed at end

   e. little contribution to blood pumping at rest; may contribute 10-20% to ventricular filling in exercise when heart rate is higher

   f. decreasing aortic (and pulmonic) pressure because blood is flowing from the arteries into the peripheral vascular beds and no blood is being ejected from the heart

   g. QRS begins




2. Isovolumetric contraction

   a. initiated by ventricular excitation (QRS wave)

   b. mitral and tricuspid valves close because of pressure gradient (aortic and pulmonic valves already closed)

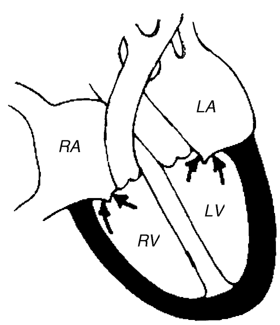
   c. rapid rise in ventricular pressure

d. no change in ventricular volume (isovolumetric = constant volume)

   e. decreasing aortic (and pulmonic) pressure

   f. atrial pressures may increase due to bulging of A-V valves (venous "c" wave)

   g. first heart sound begins



B. Phases (continued)

3. Ventricular ejection

   a. begins when ventricular pressure exceeds aortic (or pulmonary artery) pressure

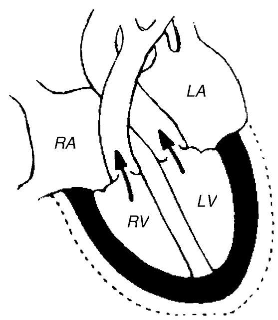
   b. aortic (and pulmonic) valves open

   c. initial rapid reduction of ventricular volume as blood is ejected from the ventricle followed by reduced ejection

   d. ventricular (and arterial) pressures increase to maximum ("systolic pressure") and then decrease slowly as the ventricular begin to relax

   e. initial low atrial pressure followed by increasing atrial pressure as the atria fill with blood returning via the veins from the peripheral vascular beds

   f. ventricular repolarization begins (T wave)




4. Isovolumetric relaxation

   a. begins when ventricular pressure drops below aortic (or pulmonary artery) pressure

   b. aortic (and pulmonic) valve closes (mitral and tricuspid already closed)

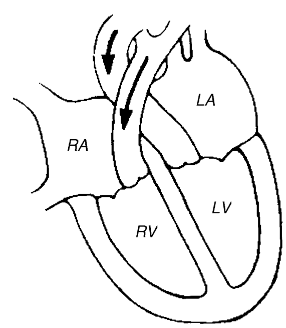
   c. rapid fall in ventricular pressure

   d. no change in ventricular volume

   e. decreasing arterial pressure

   f. increasing atrial pressure (venous "v" wave)

   g. second heart sound begins




6. Ventricular filling

   a. begins when ventricular pressure drops below atrial pressure

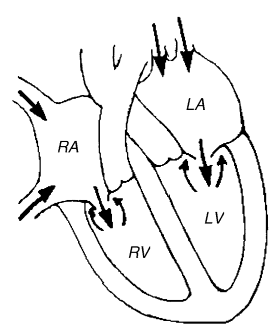
   b. mitral (and tricuspid) valves open

   c. flow of blood from atrium to ventricle, initially rapid, then slower as the ventricles fill

   d. ventricular pressure decreases and then rises slowly as the ventricles fill

   e. atrial pressure decreases initially as blood flows from the atria to the ventricles, then slowly increases

   f. arterial pressure decreases



CARDIAC CYCLE (continued)

C. Right Heart

1. Volume curve: similar in shape and amplitude and timing to left heart

2. Pressure curves: similar in shape and timing, but reduced in amplitude compared to left heart

| | |
|---|---|
| left atrium | 12/5 mmHg |
| left ventricle | 120/5 |
| aorta | 120/75 |
| right atrium | 9/2 |
| right ventricle | 22/2 |
| pulmonary arteries | 22/10 |

D. Timing

1. At rest:

| | |
|---|---|
| ventricular diastole | 65% of cycle |
| ventricular systole | 35% of cycle |

2. In exercise: both systole and diastole are reduced in duration, but diastole is reduced more

HEART SOUNDS

A. Causes

1. Rapid deceleration of blood (e.g. normal heart sounds)

2. Rapid acceleration of blood (e.g. opening snap of mitral stenosis)

3. Turbulence (e.g. murmurs)

B. Normal Heart Sounds

1. <u>First</u> heart sound ("lub"): associated with closure of the A-V valves

2. <u>Second</u> heart sound ("dub"): associated with closure of the aortic and pulmonic valves

   Note: If the A-V valves do not close at the same time, the first heart sound becomes <u>split</u>; if the aortic and pulmonic valves do not close at the same time, the second heart sound becomes <u>split</u>

3. <u>Third & Fourth</u> heart sounds: Usually not heard. Third sound during rapid filling due to blood rushing into ventricles.

CARDIAC OUTPUT (CO)

A. Define: total blood pumped by either ventricle per minute

B. Equal to the product of stroke volume (SV, blood ejected from either ventricle per beat) and heart rate (HR)

CO = SV x HR

Stroke volume is in turn equal to the End Diastolic Volume (EDV, the volume of blood in the ventricle at the end of diastole) minus the End Systolic Volume (ESV, the volume of blood in the ventricle at the end of systole):

SV = EDV - ESV

C. Normal at rest (adult of average size)

| | |
|---|---|
| EDV | = 135 ml |
| ESV | = 65 ml |
| SV | = 135 - 65 = 70 ml |
| HR | = 72/minute |
| CO | = 70ml x 72/min ≅ 5 Liters/minute |

Note: the ventricles do not empty completely at each beat; instead ejects 50-70% of its end diastolic volume blood

Ejection Fraction = SV/EDV