The Cardiac Cycle

- the events that must occur in order for the heart to pump blood
- each cycle is completed in 0.86s under resting conditions
  - assumes resting hr = 70
The Cardiac Cycle

- two important concepts:
  1. electrical events precede mechanical events
     - because the electrical events CAUSE the mechanical events
     - for example, depolarization of the atria must come just before contraction of the atria

2. valves open and close passively, based on pressure gradients on either side of the valve
   - this diagram shows the changes on the left side of the heart
     - right side is similar, but at lower pressures
The Cardiac Cycle

• Valve positions at start of cycle:
  - Left atrial pressure > left ventricular pressure
    • Mitral valve is open
      - Blood can flow from atrium to ventricle (passive filling)
  - Left ventricular pressure < aortic pressure
    • Aortic semilunar valve is closed
      - Blood cannot flow between ventricle and aorta

The Cardiac Cycle

First event in cycle:
• SA Node fires, depolarization spreads throughout atria
  - Causes P wave on ECG
• Depolarization of left atrium causes atrial contraction at about mid-point of P wave
  - Squeezes some blood from atrium into left ventricle
    • Both left atrial and left ventricular pressure go up
  - Left atrial pressure still is slightly greater than left ventricular pressure
    • Mitral valve still open
  - Left ventricular volume reaches its maximum
    • End diastolic volume
The Cardiac Cycle

Next event:
- AV Node depolarizes, then Bundle of His, AV bundles, and Purkinje fibers
  - causes depolarization of all ventricular muscle fibers
    - QRS complex on ECG
    - ventricle muscle fibers respond by contracting
      - ventricular systole

• as ventricle contracts, pressure in the left ventricle goes up
  - quickly exceeds atrial pressure
    - mitral valve closes
      - causes first heart sound
  - still less than aortic pressure
    - aortic semilunar valve still closed
• with both valves closed, blood can neither enter nor leave ventricle
  - period of isovolumic contraction
  - sometimes incorrectly called isovolumetric contraction
The Cardiac Cycle

Once ventricular pressure > aortic pressure:
- the aortic semilunar valve opens and blood can now leave the ventricle
  - period of ejection
  - ventricular volume goes down
    - biggest drop in first half of ejection
    - with exercise, the ejection time will be reduced, but ejection volume goes up as ventricular contractility is increased

The Cardiac Cycle

- ventricular pressure continues to rise as ventricle contracts
  - but eventually, pressure peaks, then falls as blood volume has dropped dramatically
  - heart muscle repolarizes while pressure is dropping, causing T wave on ECG
- about 55% of end diastolic volume is ejected under resting conditions
  - higher percentage when exercising, due to increased contractility
The Cardiac Cycle

when left ventricular pressure < aortic pressure:
- aortic semilunar valve soon closes (not immediately due to momentum of blood ejection)
  - diastolic notch as aortic blood slams back against closed valve
  - creates second heart sound
  - ejection ends
    - both valves now closed
    - heart muscle now relaxing
      - pressure in left ventricle continues to fall dramatically
  - period of isovolumic relaxation
  - volume of blood left in left ventricle is called the end systolic volume

The Cardiac Cycle

once left ventricular pressure < left atrial pressure:
- the mitral valve opens
- blood can now flow from atrium to ventricle
  - period of ventricular filling
    - highest rate of filling in first half of period
      - period will be shortened during exercise without major drop in end diastolic volume
  - cycle then repeats with next SA Node depolarization
Cardiac Output

- amount of blood ejected from ventricle in 1 minute
- product of stroke volume (amount ejected per systole) and heart rate
  - regulating cardiac output = regulating stroke volume and heart rate
- typically around 5 L/min at rest
  - \((70 \text{ ml} \cdot \text{b}^{-1}) \cdot (70 \text{ b} \cdot \text{min}^{-1}) = (4900 \text{ ml} \cdot \text{min}^{-1})\)
- can increase 5 fold during exercise
  - extra is called cardiac reserve
Regulation of Cardiac Output

- regulation of stroke volume
  - typically, heart ejects 55% of end diastolic volume
    - ejection fraction = 0.55
  - three factors affect stroke volume:
    1. Preload
    2. Contractility
    3. Afterload

Regulation of Cardiac Output

1. preload:
   - stretch on heart muscle by end diastolic volume
   - Frank-Starling Law of the Heart:
     - within limits, an increase in preload stretches myocardial fibers, giving better overlap of actin and myosin and hence stronger contraction.
   - venous return to heart not only stretches muscle, but it determines the amount of blood that is available for ejection
     - muscle pump and thoracic pump increase venous return
Regulation of Cardiac Output

2. contractility
   • the strength of contraction
     – can be increased by sympathetic nervous system stimulation
     – also increased by any drug that increases the length of time L-type Ca\(^{2+}\) channels are open
       » positive inotropic agents

3. afterload: the pressure that the ventricle must exceed in order to open aortic semilunar valve and eject blood (equals diastolic pressure)

Regulation of Cardiac Output

• regulation of heart rate
  – sympathetic and parasympathetic nervous systems
  – baroreflex
  – chemoreflex