Electrical Activity of Conduction System Coordinates Mechanical Activity of Pumping

Conduction System of Heart: Coordinates Atrial and Ventricular Excitement to Optimize Blood Pumping
Cardiac Cycle – Mechanical Events of SYSTOLE (Pumping)

Rapid increase in pressure \(\rightarrow\) open aortic valve \(\rightarrow\) eject blood into aorta

### Isovolumetric ventricular contraction
- Atria relaxed
- Ventricles contract

### Ventricular ejection
- Blood flows out of ventricle
- Atria relaxed
- Ventricles contract

<table>
<thead>
<tr>
<th>AV valves</th>
<th>Closed</th>
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<tbody>
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<td>Aortic and pulmonary valves</td>
<td>Closed</td>
<td>Open</td>
</tr>
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</table>
Cardiac Cycle – Mechanical Events

Close Aortic Valve ➔ relax contraction ➔ open a-v (mitral) valve ➔ passively fill ventricle ➔ actively fill ventricle (atrial contraction)

Mid- Ventricular Diastole
1. Atrial P > Vent P, a-v open
2. Reduced late slow passive ventricular filling

Late Ventricular Diastole
3. ECG P wave = atrial contracts
4. Increase atrial pressure
5. Increase ventric pressure (a>v)
6. Active ventricular filling

End of Ventricular Diastole
7. Ventricle full for cycle EDV = 135 ml
**Ventricular Excitation = Systole**

8. QRS = ventricular excitation
9. Ventricular Contraction ➔ ventricular press > atrial press, close a-v valve, first heart sound (lub)

**Isovolumetric Contraction**

10. Rapid increase ventricular press
11. All valves closed, no Δ in volume

**Ventricular Ejection**

13. Aortic pressure increases but < ventricular pressure
14. Ventricular volume decreases

**End of Ventricular Systole**

15. 70 ml SV ejected, ESV remains (65ml) SV = EDV-ESV
   \[70 = 135 - 65\]

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**Ventricular Repolarization – Onset of Ventricular Diastole**

16. T wave = ventricular repolarization
18. Dicrotic notch as aortic pressure briefly decreases

**Isovolumetric Relaxation (diastole)**

19. Rapid decrease in aortic pressure, both valves closed
20. No change in ventricular volume

**Early Ventricular Filling (diastole)**

21. Atrial Pressure > Ventricular Pressure = a-v valve opens
22. Atrial Pressure increased by blood from pulmonary artery
23. Rapid early passive filling

**Mid Ventricular Diastole**

24. Reduced late passive filling

**Late Ventricular Diastole**

25. SA node ➔ P wave
**Cardiac Output** = 5 liters per minute = 5000ml per minute

- Volume of blood ejected by each ventricle each minute
- Determined by **heart rate** times **stroke volume**

**HEART RATE** = beats / minute = 70bpm
**STROKE VOLUME** = ml or Liters per beat = 70 ml/beat

\[
\text{CO} = 5000 \text{ ml/min} = 70 \times 70 = 71 \times 71 = 70 \times 71 = \text{etc}
\]
\[
4900 = 5041 = 4970 = \text{etc}
\]
CO = HR x SV

- Heart rate is varied by altering balance of parasympathetic and sympathetic influence on SA node
  - Parasympathetic stimulation slows heart rate 70 to 60 to 50
    - Removal speeds HR 70 to 80 to 90 to 100 (rate with complete ps blockage)
  - Sympathetic stimulation speeds it up
    - 70 to max HR = ~ 220 – age for population
      HR > 100 has to be sympathetic or adrenal catecholamine effect

KEY
- Inherent SA node pacemaker activity
- SA node pacemaker activity on parasympathetic stimulation
- SA node pacemaker activity on sympathetic stimulation

(a) Autonomic influence on SA node potential

Fig. 9-17a, p. 248
(b) Control of heart rate by autonomic nervous system

Fig. 9-17b, p. 248
CO = HR \times SV

- **Stroke volume**
  - Determined by extent of venous return and by sympathetic activity
  - Influenced by two types of controls
    - Intrinsic control
    - Extrinsic control
  - Both factors increase stroke volume by increasing strength of heart contraction

Fig. 9-18, p. 249
Cardiac Reserve = Max CO/Rest CO

Frank-Starling curve on sympathetic stimulation
Normal Frank-Starling curve

Increase in stroke volume at same end-diastolic volume

End-systolic volume
End-diastolic volume

(a) Normal stroke volume
Stroke volume 70 ml
End-systolic volume 65 ml
End-diastolic volume 135 ml

(b) Stroke volume during sympathetic stimulation
Stroke volume 100 ml
End-systolic volume 35 ml
End-diastolic volume 135 ml

(c) Stroke volume with combination of sympathetic stimulation and increased end-diastolic volume
Stroke volume 140 ml
End-systolic volume 35 ml
End-diastolic volume 175 ml

Fig. 9-20, p. 250
Ejection Fraction

- One way to quantify contractility is through the ejection fraction (EF), defined as the ratio of stroke volume (SV) to end-diastolic volume (EDV):
  - \[ \text{EF} = \frac{\text{SV}}{\text{EDV}} = \frac{70\text{ml}}{135\text{ml}} = 51\% \]
  - \[ \text{EF} = \frac{\text{SV}}{\text{EDV}} = \frac{70\text{ml}}{120\text{ml}} = 58\% \]

- Expressed as a percentage, the ejection fraction normally averages between 50 and 75 percent under resting conditions.

- Increased contractility causes an increased ejection fraction.

Preload and Afterload

- Preload is proportional to the amount of ventricular myocardial fiber stretch just before systole (EDV)
  - The “load” that the heart must pump out
  - Increase preload, increase contractile force, increase heart “work” (volume overload) ... force development assisted by Starling Mechanism

- Afterload is the pressure that the ventricles must overcome to force open the aortic and pulmonary valves.
  - Anything that increases systemic or pulmonary arterial pressure can increase afterload.

  ➔ Afterload, increase contractile force necessary, increase heart work (pressure overload) .... Force development not assisted by Starling Mechanism
Normal College Male

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<th>End Systolic Volume</th>
<th>Stroke Volume (ml/stroke)</th>
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<td>60</td>
<td>150</td>
<td>65</td>
<td>85</td>
<td>5100</td>
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<tr>
<td>Sitting Rest</td>
<td>72</td>
<td>135</td>
<td>65</td>
<td>70</td>
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<tr>
<td>Stand Rest</td>
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<tr>
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<td>150</td>
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<td>8500</td>
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<tr>
<td>Jogging</td>
<td>120</td>
<td>150</td>
<td>65</td>
<td>100</td>
<td>12000</td>
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<tr>
<td>Mile Run</td>
<td>190</td>
<td>155</td>
<td>50</td>
<td>105</td>
<td>19950</td>
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Strokes/min x ml/stroke = ml/min
Heart Rate x stroke volume = cardiac output

Trained College Athlete – male basketball player

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Strokes/min x ml/stroke = ml/min
Heart Rate x stroke volume = cardiac output
**World Class Cross Country Ski Racer**

Champion endurance athletes have had cardiac output of 40 liters during maximal exercise.

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\[ \text{Lower Max HR} \]

\[ \text{Strokes/min} \times \text{ml/stroke} = \text{ml/min} \]

\[ \text{Heart Rate} \times \text{stroke volume} = \text{cardiac output} \]