Cardiac Muscle Physiology

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Objectives:

By the end of this lecture, students should be able to:

- Distinguish the cardiac muscle cell microstructure
- Describe cardiac muscle action potential
- Point out the functional importance of the action potential
- Outline the intracellular calcium homeostasis
Wall of the heart

- Fibrous pericardium
- Parietal layer of serous pericardium
- Visceral layer of serous pericardium (epicardium)
- Pericardial cavity
- Endocardium
- Myocardium (cardiac muscle)
- Trabeculae carnea

Cardiac Muscle Cells

- Capillary
- Desmosomes
- Intercalated discs
- Sarcolemma
- Nucleus
- Cardiac muscle fiber
- Gap junction
(a) Cardiac muscle fibers

(b) Diagram based on an electron micrograph
Permeability Changes and Ionic Fluxes During an Action Potential (skeletal Muscle)
Plateau (maintained depolarization) due to opening of voltage-gated slow Ca\(^{2+}\) channels and closing of some K\(^+\) channels

1. Rapid depolarization due to opening of voltage-gated fast Na\(^+\) channels

2. Repolarization due to opening of voltage-gated K\(^+\) channels and closing of Ca\(^{2+}\) channels

0.3 sec = 300 msec

(a) Action potential, refractory period, and contraction

(b) Membrane permeability (P) changes
The Action Potential in Skeletal and Cardiac Muscle

**Figure 20.15**

**STEP 1: Rapid Depolarization**
- Cause: $\text{Na}^+$ entry
- Duration: 3–5 msec
- Ends with: Closure of voltage-regulated (fast) sodium channels

**STEP 2: The Plateau**
- Cause: $\text{Ca}^{2+}$ entry
- Duration: ~175 msec
- Ends with: Closure of slow calcium channels

**STEP 3: Repolarization**
- Cause: $\text{K}^+$ loss
- Duration: 75 msec
- Ends with: Closure of slow potassium channels

**Cardiac Muscle**

- Stimulus
- Absolute refractory period
- Relative refractory period

**Skeletal Muscle**

- Action potential
- Tension
- Contraction

Time (msec): 0 to 300

(a) Cardiac muscle

(b) Skeletal muscle
Tetanus in a skeletal muscle. Action potentials not shown.

**Tension**

- Refractory period
- Maximum tension

▲ = Stimulus for action potential

Time (msec) 0 75 150
Long refractory period in a cardiac muscle prevents tetanus.

- Refractory period

Membrane potential (mV)

Tension

-90 0 250 0

Time (msec)
Functional importance of Cardiac action potential

- The decrease in conductance (permeability) of potassium at phase 0 and 1 of the cardiac action potential contributes to the maintenance of depolarization in phase 2 (plateau).
- The long absolute refractory period prevent the occurrence of tetanus (maintained contraction without a period of relaxation) in the cardiac muscle.
- Skeletal muscle action potential is short that allows tetanus to occur.
Activation gates open when the membrane potential becomes less negative and the inactivation gates close when the potential becomes less negative. The activation gate is fast but the inactivation is slow responding.
PHASE 0 OF THE FAST FIBER ACTION POTENTIAL

A. -90mv
B. -65mv
C. 0mv
D. +20mv
E. +30mv

Chemical Gradient
Electrical Gradient

Na⁺
Membrane potential (mV)

Time (msec)

<table>
<thead>
<tr>
<th>Phase</th>
<th>Membrane channels</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>Na(^+) channels open</td>
</tr>
<tr>
<td>1</td>
<td>Na(^+) channels close</td>
</tr>
<tr>
<td>2</td>
<td>Ca(^{2+}) channels open; fast K(^+) channels close</td>
</tr>
<tr>
<td>3</td>
<td>Ca(^{2+}) channels close; slow K(^+) channels open</td>
</tr>
<tr>
<td>4</td>
<td>Resting potential</td>
</tr>
</tbody>
</table>
The importance of calcium influx through the slow voltage gated calcium channels

1. Action potential enters from adjacent cell.
2. Voltage-gated Ca$^{2+}$ channels open. Ca$^{2+}$ enters cell.
3. Entry of Ca$^{2+}$ triggers release of Ca$^{2+}$ from sarcoplasmic reticulum.
4. Most Ca$^{2+}$ comes from the SR.
5. Ca$^{2+}$ ions bind to troponin to initiate contraction.
6. Relaxation occurs when Ca$^{2+}$ unbinds from troponin.
7. Ca$^{2+}$ is pumped back into the sarcoplasmic reticulum for storage.
8. Ca$^{2+}$ is exchanged with Na$^+$. 
9. Na$^+$ gradient is maintained by the Na$^+$-K$^+$-ATPase.
Mechanism of Cardiac Muscle Excitation, Contraction & Relaxation

1. Action potential enters from adjacent cell.
2. Voltage-gated Ca$^{2+}$ channels open. Ca$^{2+}$ enters cell.
3. Ca$^{2+}$ induces Ca$^{2+}$ release through ryanodine receptor-channels (RyR).
4. Local release causes Ca$^{2+}$ spark.
5. Summed Ca$^{2+}$ sparks create a Ca$^{2+}$ signal.
6. Ca$^{2+}$ ions bind to troponin to initiate contraction.
7. Relaxation occurs when Ca$^{2+}$ unbinds from troponin.
8. Ca$^{2+}$ is pumped back into the sarcoplasmic reticulum for storage.
9. Ca$^{2+}$ is exchanged with Na$^+$. 
10. Na$^+$ gradient is maintained by the Na$^+$-K$^+$-ATPase.
Intracellular Calcium Homeostasis...
Intracellular Calcium Homeostasis...2
Cardiac Muscle action potential Vs. Skeletal Muscle

- Phase 0 – Depolarization phase (Na\(^+\) influx)
- Phase 1 partial repolarization (Not in skeletal)
- Phase 2 Plateau (~ depolarization not in skeletal) slow calcium channels
- Phase 3 fast repolarization phase (K\(^+\) repolarization)
- Phase 4 resting membrane potential
Thank You