Cardiac Muscle

- Cardiac muscle cells have one to two nuclei that are centrally located.
- They are striated and use the sliding filament mechanism to contract.
- They are branching cells with intercalated discs with desmosomes and gap junctions. The gap junctions are critical to the heart’s ability to be electrically coupled.
- They have large mitochondria that produce the energy needed and prevent the heart from fatiguing.
- The node cells have the ability to stimulate their own action potentials. This is called automaticity or autorhythmicity.
- The absolute refractory period is about 250 ms. This prevents tetanic contractions which would interfere with the heart’s ability to pump.
**Excitation-Contraction Coupling in Cardiac Muscle**

- "Excitation" (depolarization of plasma membrane)
- Opening of plasma membrane L-type Ca^{2+} channels in T-tubules
- Flow of Ca^{2+} into cytosol
- Ca^{2+} binds to Ca^{2+} receptors (ryanodine receptors) on the external surface of the sarcoplasmic reticulum
- Opening of Ca^{2+} channels intrinsic to these receptors
- Flow of Ca^{2+} into cytosol
- ↑ Cytosolic Ca^{2+} concentration
- Multiple steps
- Contraction

**Skeletal vs Cardiac Muscle**

**Skeletal muscle**
- Membrane potential (mV)
- Muscle tension

**Cardiac muscle**
- Membrane potential (mV)
- Muscle tension
- Refractory period
Nourishing the Heart Muscle

- Muscle is supplied with oxygen and nutrients by blood delivered to it by coronary circulation, not from blood within heart chambers.
- Heart receives most of its own blood supply that occurs during diastole.
  - During systole, coronary vessels are compressed by contracting heart muscle.
- Coronary blood flow normally varies to keep pace with cardiac oxygen needs.

Increase heart work, increase $O_2$ use

+ rate, + pressure = + work
Cardiac Muscle Metabolism

- **Glucose**
  - Uptake is insulin and activity dependent (insert GLUT transporters)
  - Provides ATP through glycolysis and oxidative phosphorylation

- **Lactate**
  - Uptake is gradient dependent (more blood lactate, more uptake)
  - Transferred to mitochondria for further metabolism

- **Fatty Acids**
  - Oxidative metabolism accounts for 98% of ATP supply
  - Mitochondria compose 40% of heart volume

**Key Points**
- Little stored glycogen, some stored tryglyceride
- Oxidative phosphorylation in mitochondria
- glycolysis
- Lactate uptake
- Fatty acid metabolism

**Diagram**:
- Glucose enters mitochondria via pyruvate
- Lactate is transported to mitochondria
- Fatty acids are metabolized
- ATP is produced through oxidative phosphorylation
- Mitochondria: site of oxidative phosphorylation

**Equations**:
- Glucose $\rightarrow$ Pyruvate $\rightarrow$ Fatty Acids
- ATP production

**Key Terms**:
- Glucose
- Lactate
- Fatty Acids
- ATP
- Oxidative phosphorylation
- Mitochondria

**Diagram Notes**:
- Contractile work, SR Ca²⁺ uptake, ion homeostasis
- Metabolism diagram showing pathways and key components.
Cardiac Muscle Metabolism

• Resting Heart oxidizes mainly fatty acid
• Working Heart oxidizes more glucose and lactic acid... during exercise lactic acid from skeletal muscle is a major cardiac muscle fuel source
  • Contraction stimulates glucose uptake by inserting more transporters
  • Force of contraction improves with CHO / LA use
  • Under perfused hearts increase reliance on glycolysis to lactate and can’t send lactate to mitochondria for oxidation
  • After re-perfusion, diseased hearts increase reliance on FFA
    – Re-perfused hearts cannot switch as well to CHO use so do not improve performance
    – Medications that block FFA use and switch on CHO use improve cardiac performance

Cardiac Muscle

• Length – Tension Relationship
  – Increase length
  – Increase stretch of myocardial cells (myocardium)
  – Increase contraction force
  – Stretch is by blood returning to heart
  – Contraction force increases to automatically pump out all blood that is returned to the heart
  – Frank Starling Law of the Heart
  – Frank Starling Mechanism
Frank-Starling Law of the Heart

- States that heart normally pumps out during systole the volume of blood returned to it during diastole
- Describes the relationship between the EDV (end diastolic volume) and stroke volume.
- Within physiologic limits, heart pumps out all of the blood returned to it with no build up of excess blood in the ventricle.

![Diagram of Frank-Starling Law of the Heart]

(a) Normal stroke volume
(b) Stroke volume during sympathetic stimulation
(c) Stroke volume with combination of sympathetic stimulation and increased end-diastolic volume
Frank–Starling curve on sympathetic stimulation

Increase in stroke volume at same end-diastolic volume

Normal Frank–Starling curve

End-diastolic volume

(a) Reduced contractility in a failing heart

(b) Compensation for heart failure
Stroke volume

(a) Reduced contractility in a failing heart

(b) Compensation for heart failure
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| Clear-Cut Length–Tension Relationship | Yes | No | No | Yes |