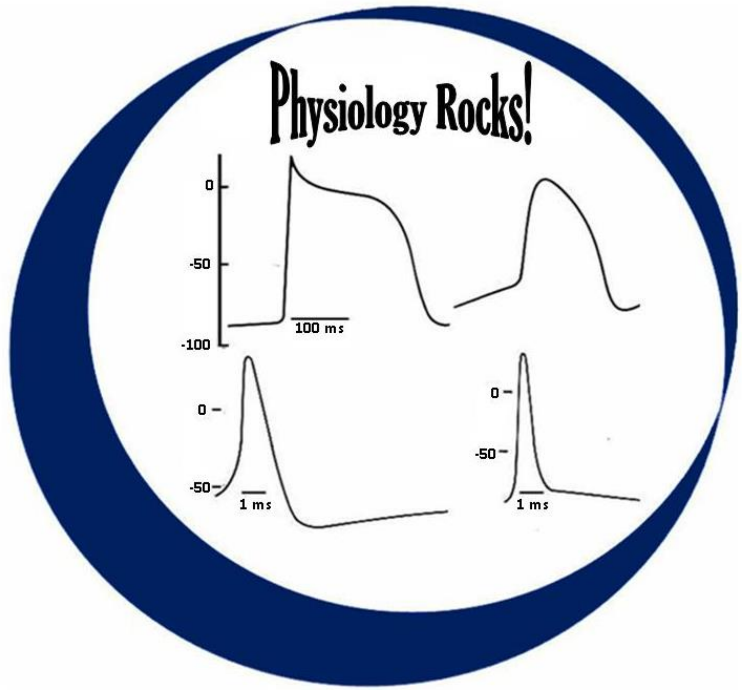
Lecture 7
Cardiac Electromechanical Activities



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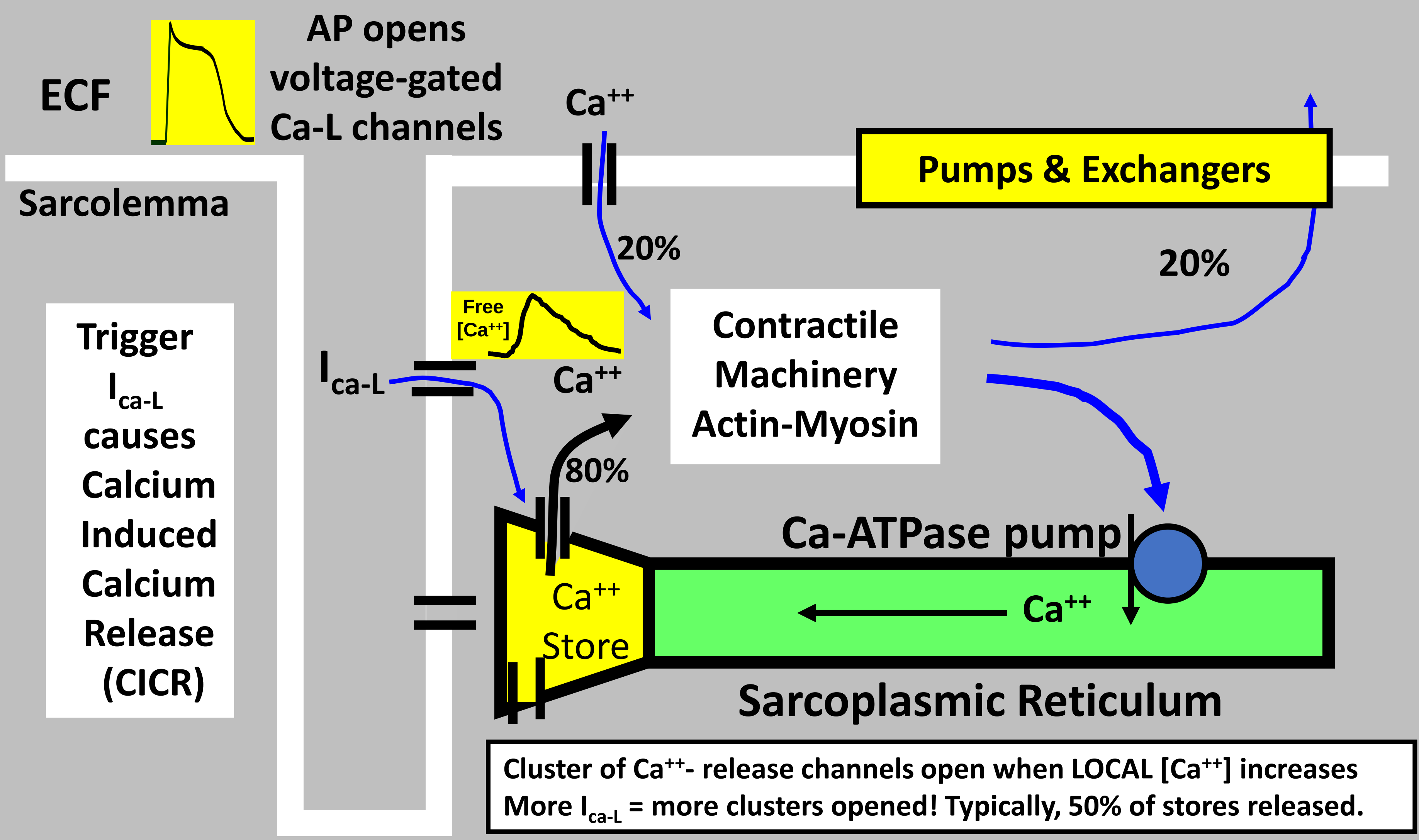
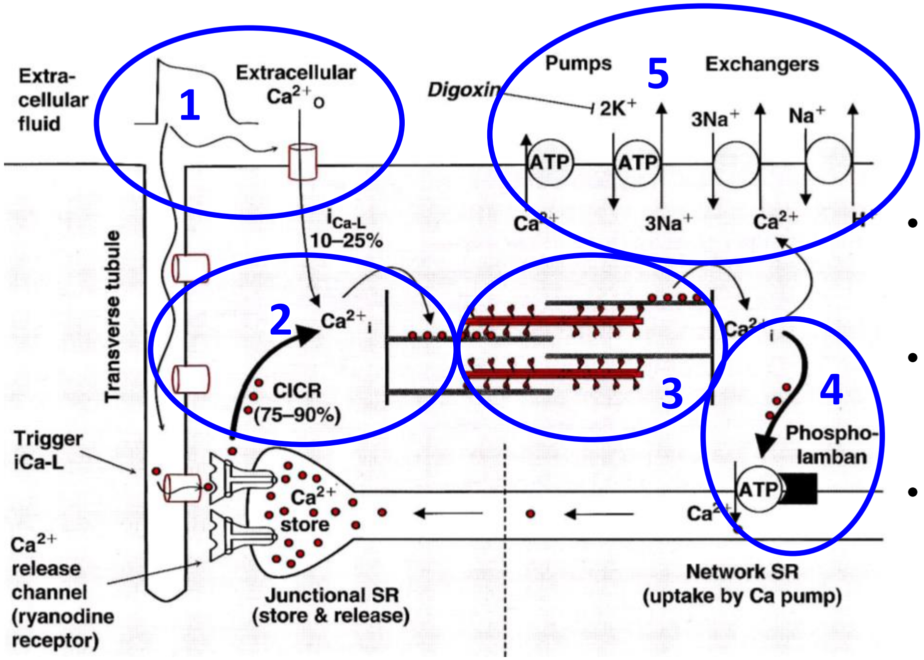
Topics

- Electrical excitation-contraction coupling
- Preload – afterload and contractility concepts
- Electrical – mechanical interactions and effects
- Prelude to cardiac dynamics
  1. Pre-ejection period
  2. Left ventricular ejection time
  3. Systolic time interval
  4. Isovolumic contraction time
- Transthoracic impedance cardiography application
- Interactive multiple-choice review questions

Excitation-Contraction Coupling: Overview



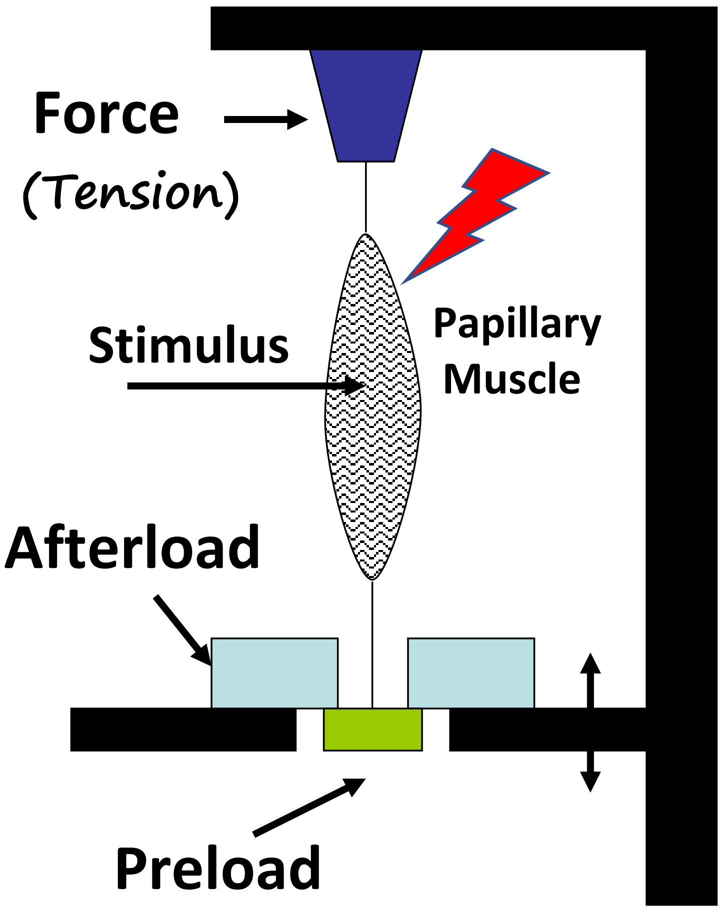
Excitation-Contraction Coupling: Calcium Cycle

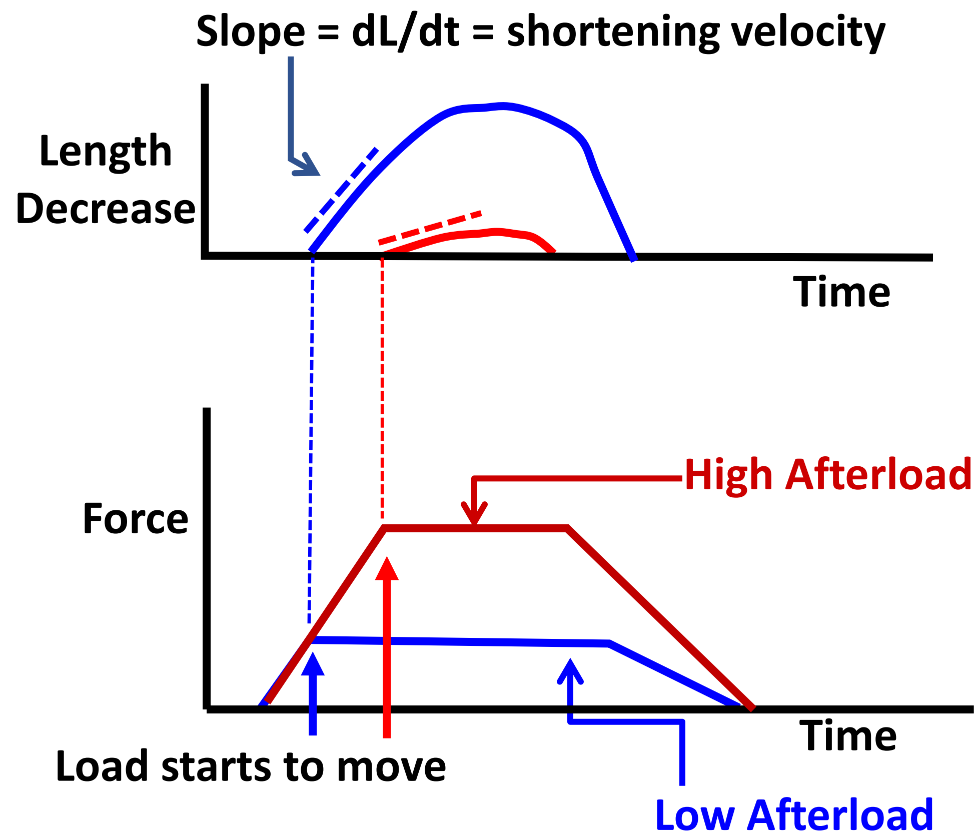


- (1) **Arriving AP** causes partial depolarization triggering Ca^{++} entry → **trigger calcium**
- (2) **Trigger Ca^{++}** causes **bursts of Ca^{++} release** for Ca^{++} stores, → **calcium induced calcium release**
- (3) **Summed Ca^{++}** activates contractile machinery → Calcium release is not all-or-none but is graded **more trigger calcium → more calcium release**
- (4) **Ca^{++} reuptake** (75-90%) via Ca^{++}-ATPase pump action with Ca^{++} stored in sarcoplasmic reticulum (SR) for subsequent **release on arrival of the next AP.** Increased cytosolic Ca^{++} reduces inhibitory action of PLB → facilitates Ca^{++} uptake
- (5) Some Ca^{++} is expelled via the pumps and exchangers Combined **decrease in Ca^{++} promotes Relaxation**

- Phospholamban's inhibitory action on SR Ca^{++} pumps is reduced with **epinephrine (E) and norepinephrine (NE)** → **increased relaxation rate** → **positive lusitropy**
- **E and NE increase trigger Ca^{++}** → increases contraction strength via (1) more Ca^{++} release and (2) more Ca^{++} stored → **positive inotropy**
- **Digoxin** (**cardiac glycoside**) partially inhibits the K^+-Na^+ pump causing increased subsarcolemmal [Na^+] that then reduces the transmembrane Na^+ gradient that drives the Na^+-Ca^{++} exchanger. **Net result is increase [Ca^{++}]** and **increased myocardial contractility**

Preload and Afterload Dependency





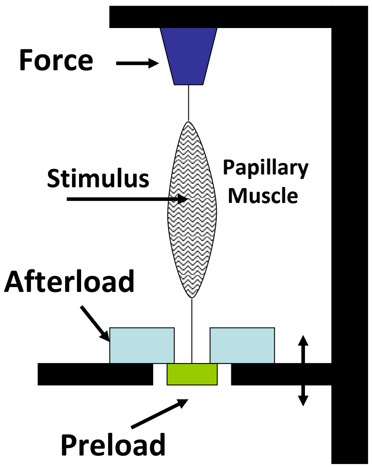
+Afterload → -Shortening Velocity

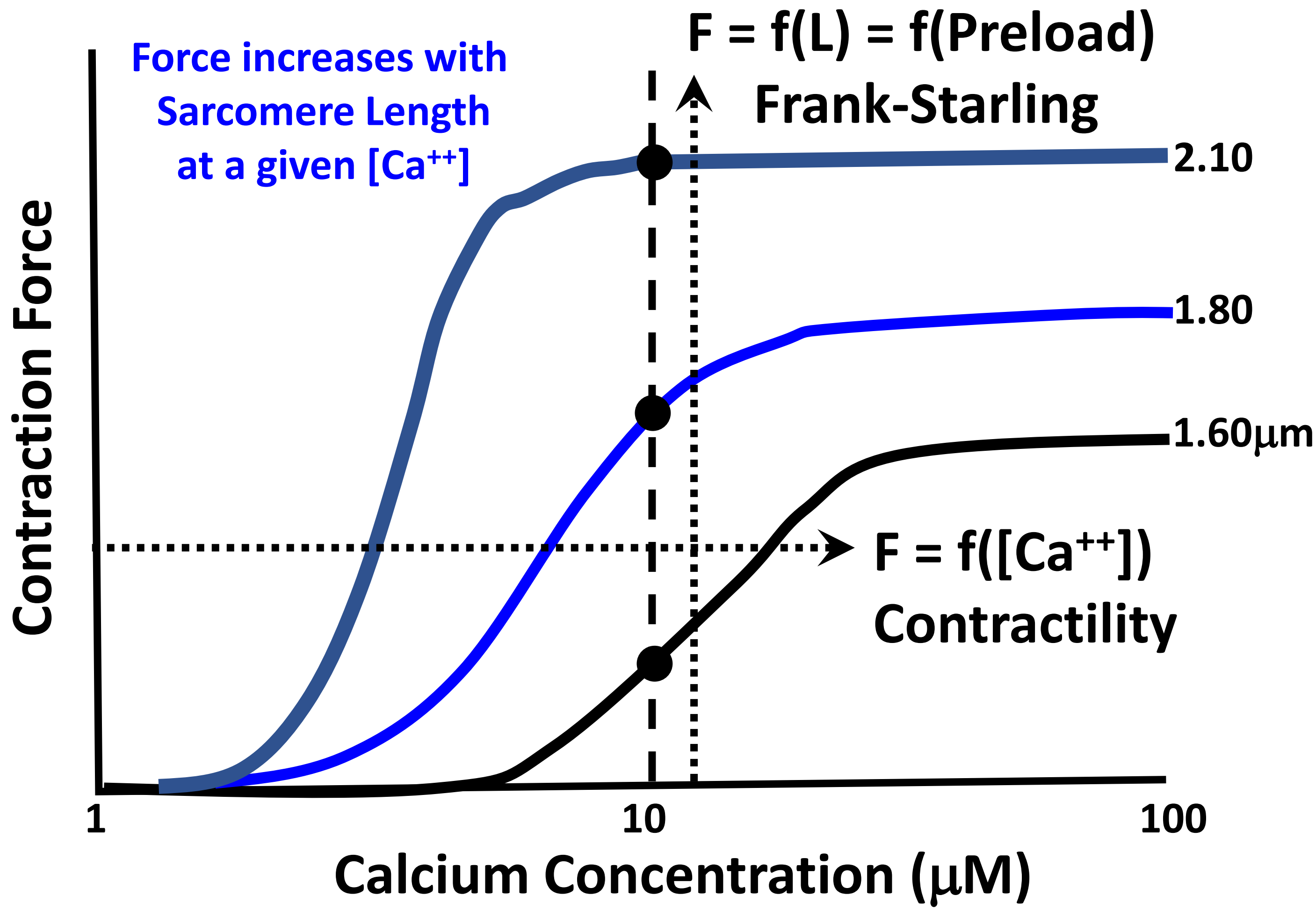
Preload = Initial Stretch

Afterload = Load to Move

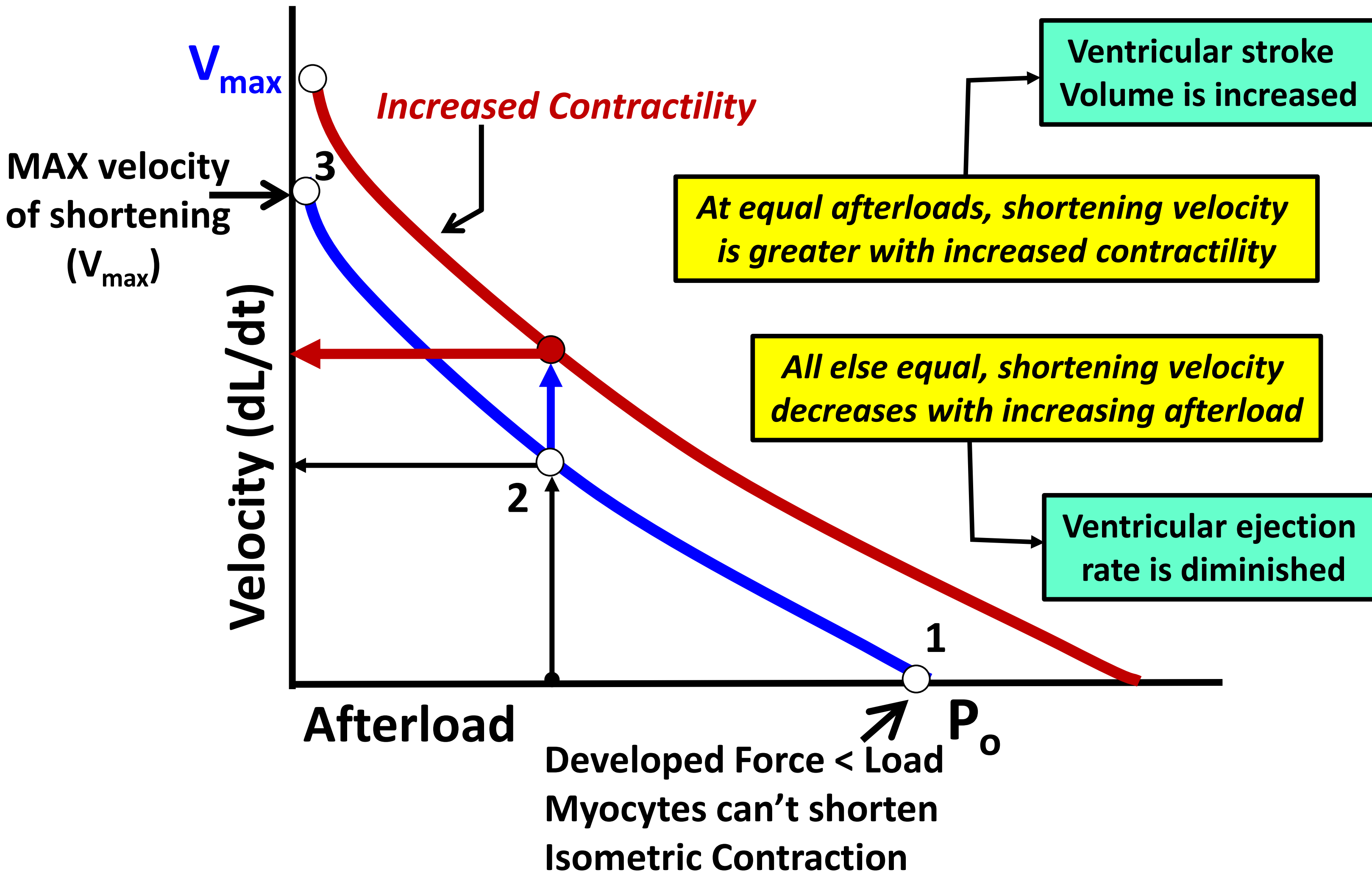
Contraction Force → Preload and Contractility $[Ca]^{++}$

Contraction force increases with increasing $[Ca^{++}]$ at a fixed sarcomere length





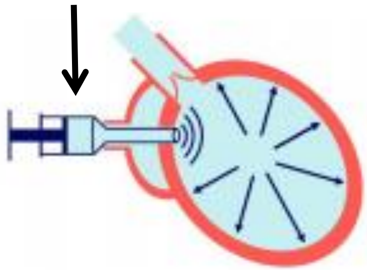
Shortening Velocity: Afterload and Contractility



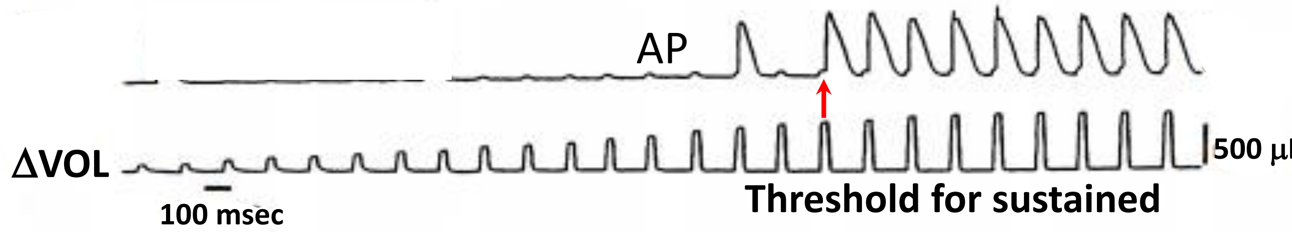
Mechanical Events May Trigger Electrical Events

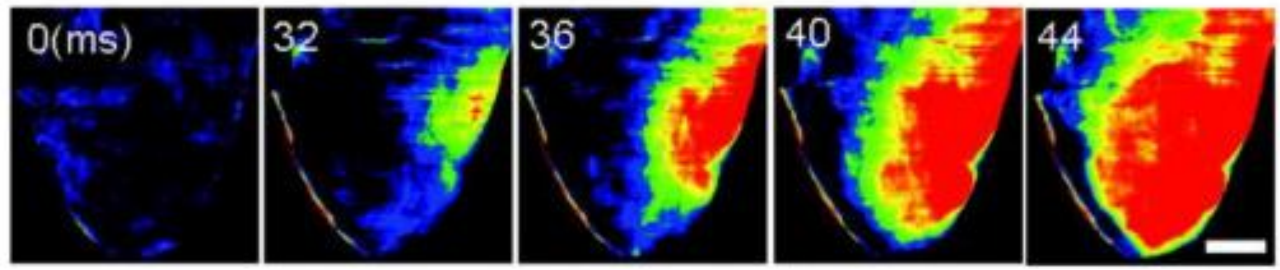
Measured Action Potentials on Epicardium of the LV

Balloon in LV inflated to increasing volumes



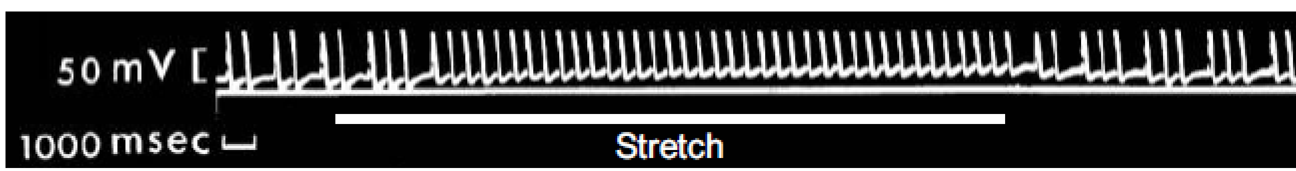
Isolated rabbit heart
Quinn Phys Rev 2021;101: 37–92





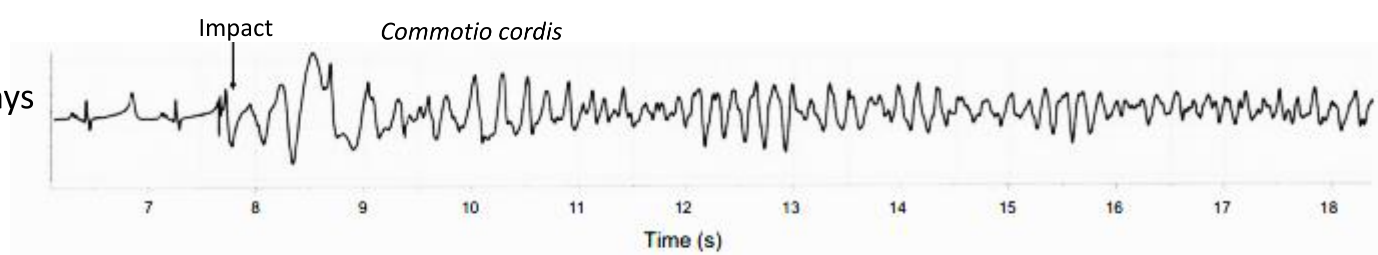
Depolarization time (msec) response to ONE SUPRATHRESHOLD inflation
Green = depolarization start, Red = depolarized

Isolated cat SA Node
Lange AJP 1996;211:1192-1196

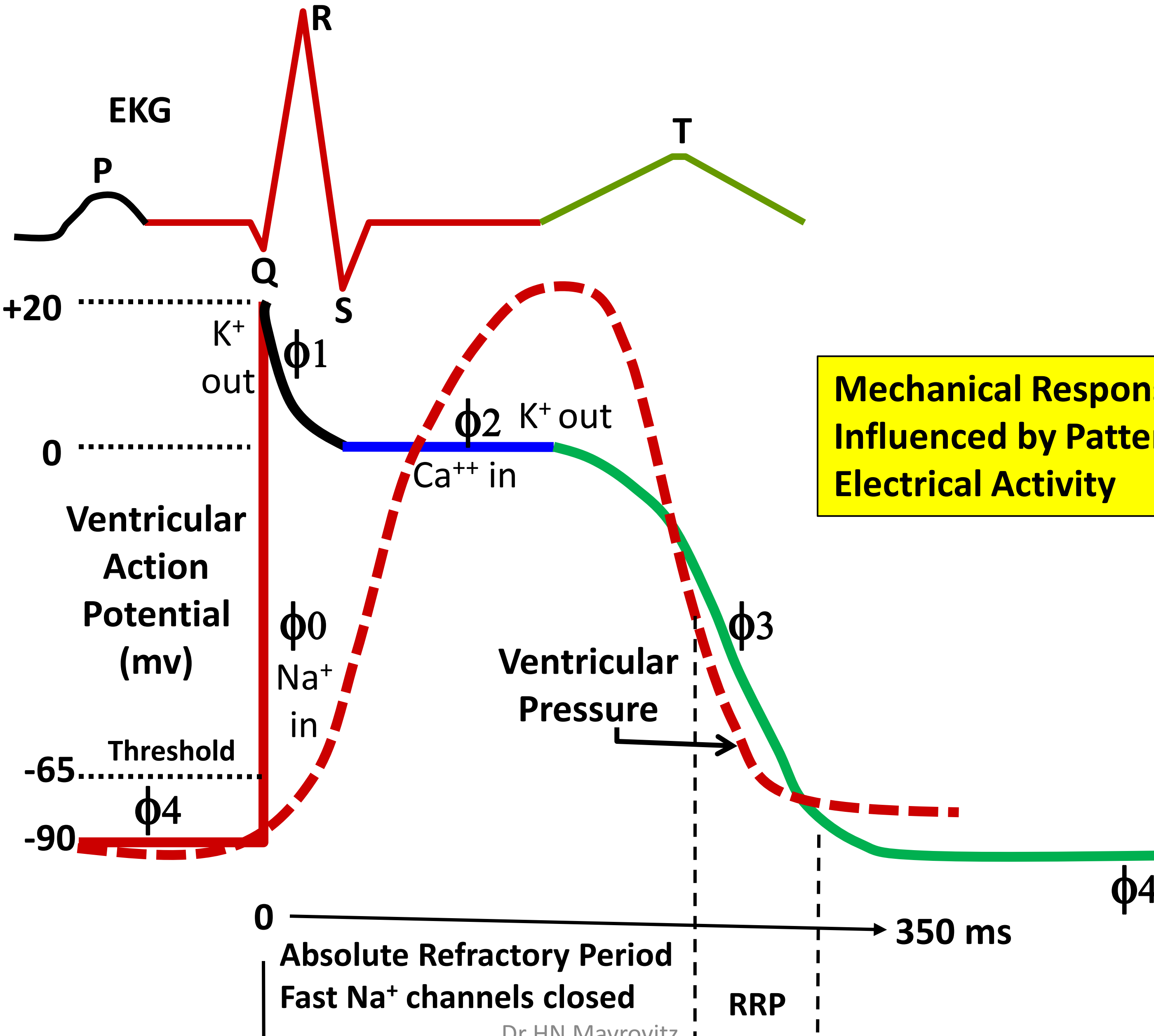


Stretch Activated Channels

Anesthetized Pig
Link Cir arrhythm Electrophys 2012;5:425-433



EKG - AP - Mechanical Overview



Mechanical Responses are Influenced by Patterns of Electrical Activity

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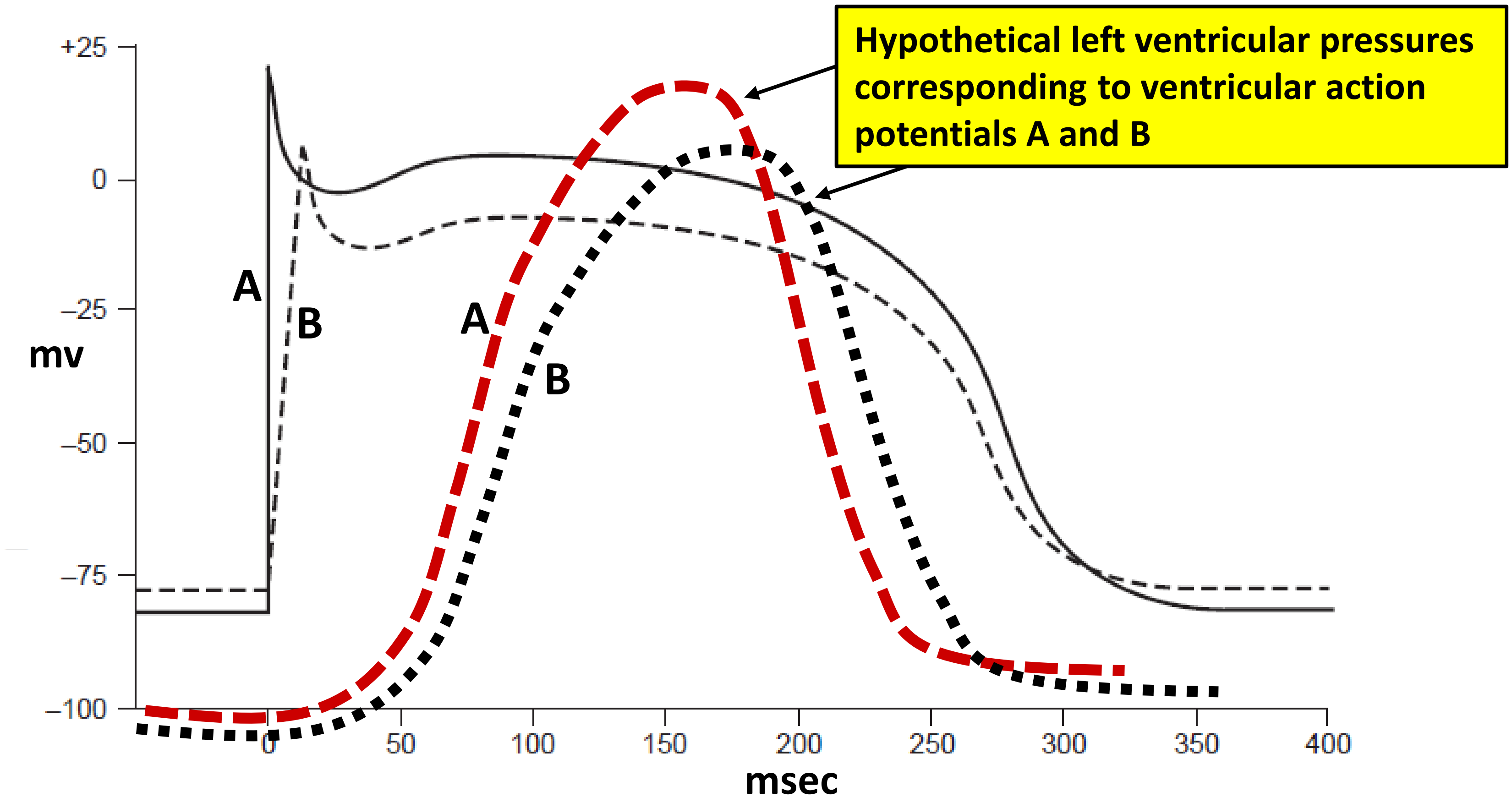
Action Potential Features Impact Mechanical Events

Rate of rise, amplitude, and width impacted by ϕ4 potential

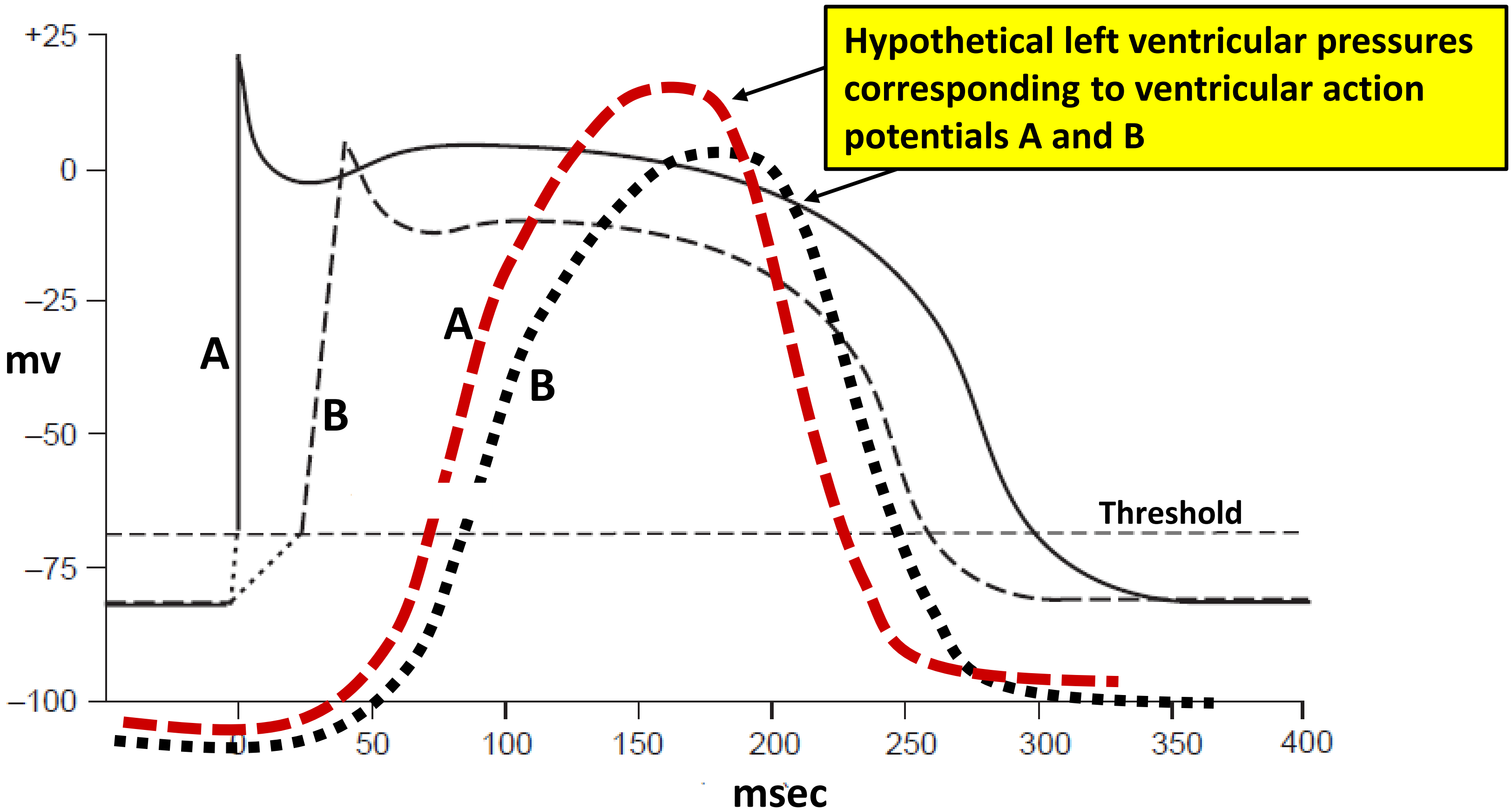
Partial depolarization (B) decreases each of these parameters and impacts ventricular pressures accordingly



Action Potential Features Impact Mechanical Events

Rate of rise, amplitude and width impacted by initial ϕ0 depolarization rate

Slower depolarization (B) decreases each of these parameters and impacts ventricular pressures accordingly



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EKG-Systolic Pre-Ejection Period and Time Intervals

Prelude to Cardiac Cycle Aspects

PEP: Pre-ejection period

(Q → AOV opening)

1. ED: Electromechanical delay

(Q→MV closure)

2. IC: Isovolumic contraction

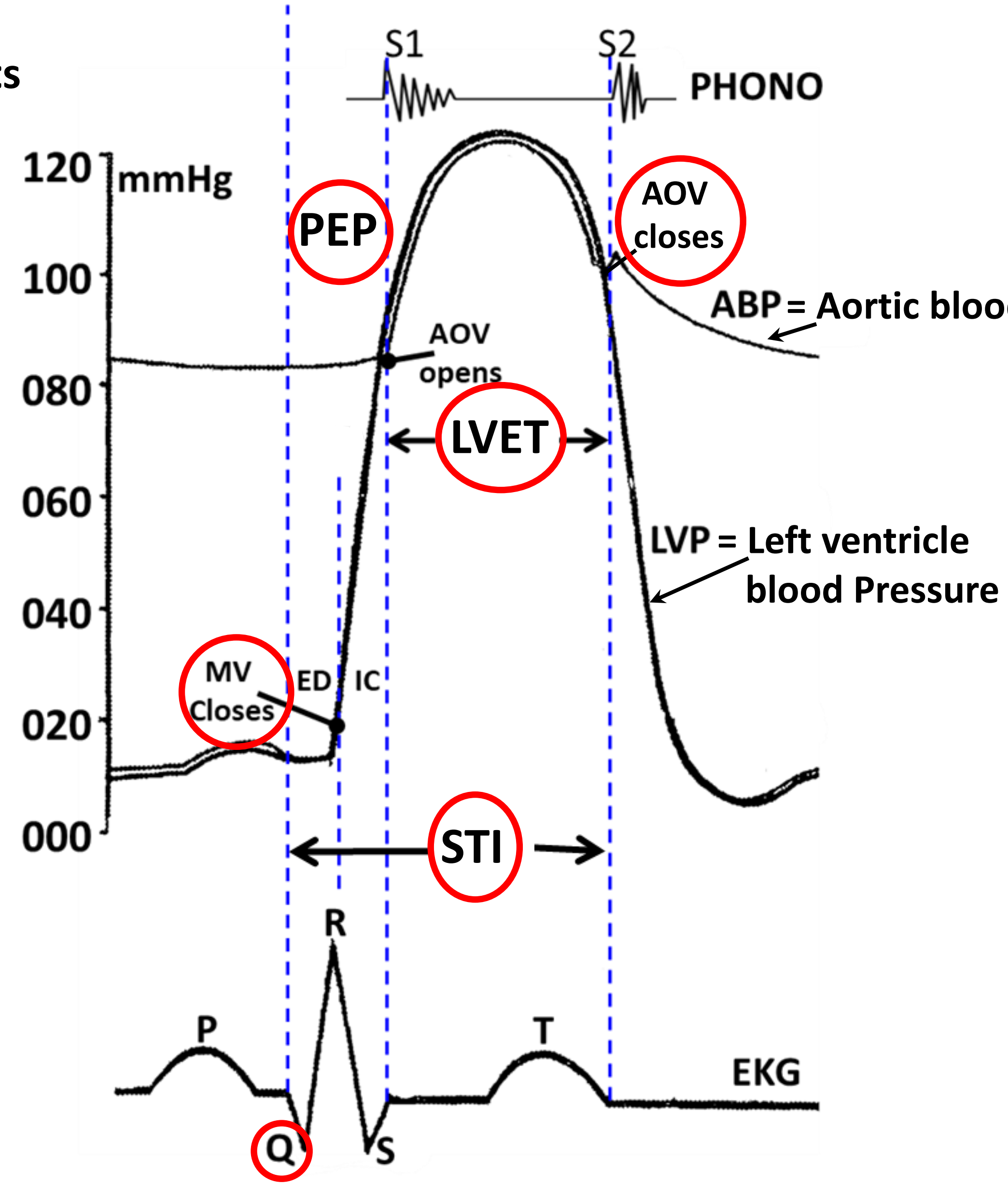
(MV closure→ AOV opens

LVET: Left ventricle ejection time

LVET: (AOV opens → AOV closes)

STI: Systolic time interval

= PEP + LVET



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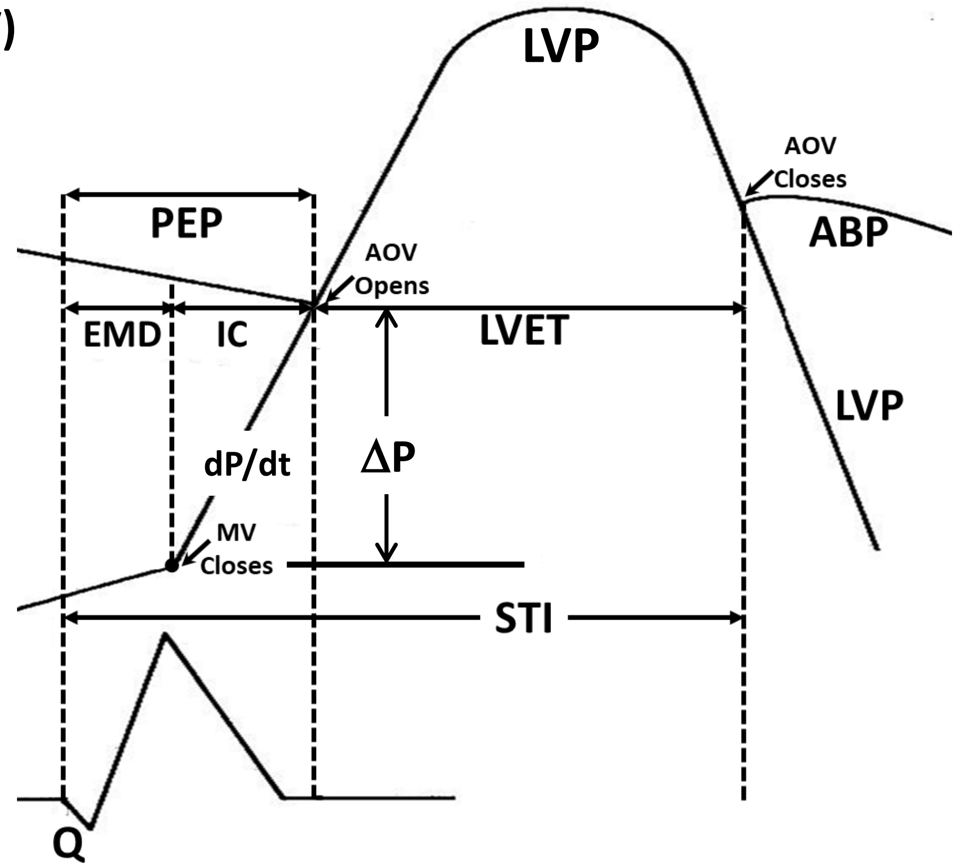
PEP and LVET Determinants

Healthy Ventricle → *Shorter PEP and Longer LVET* → *Normal PEP/LVET* → *0.345 ± 0.036*

Not so healthy → *Longer PEP and Shorter LVET* → *Larger PEP/LVET*

Specific factors affecting PEP are mainly those that relate to isovolumic contraction (IC):

- **Preload → End diastolic volume (EDV)**
- **Afterload → Aortic pressure**
- **Contractility → Contract rate & vigor**



Interactive Questions: PEP & LVET Determinants

Would PEP increase or decrease for the following conditions? (assuming single change)

Increased aortic diastolic BP (P_D)? ↑ Takes longer to open AOV

Increased cardiac sympathetic nerve traffic to LV? ↓ +dP/dt less time to open AOV

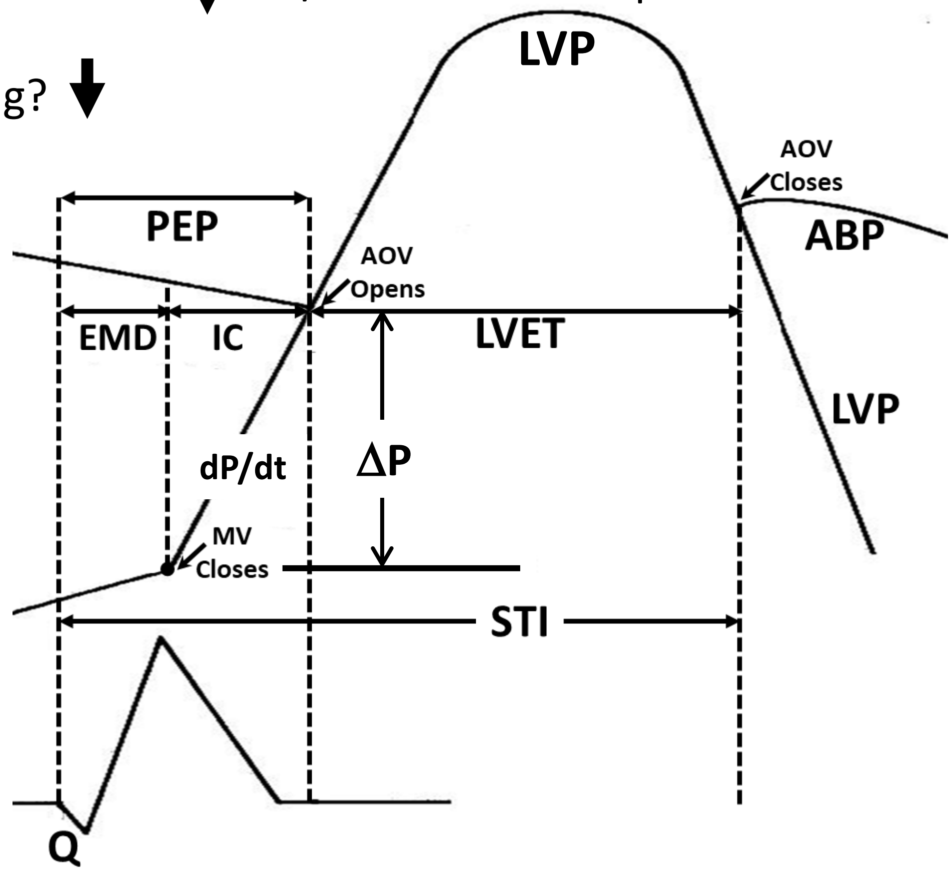
Administration of a positive inotropic drug? ↓

Increased LVEDP? ↓

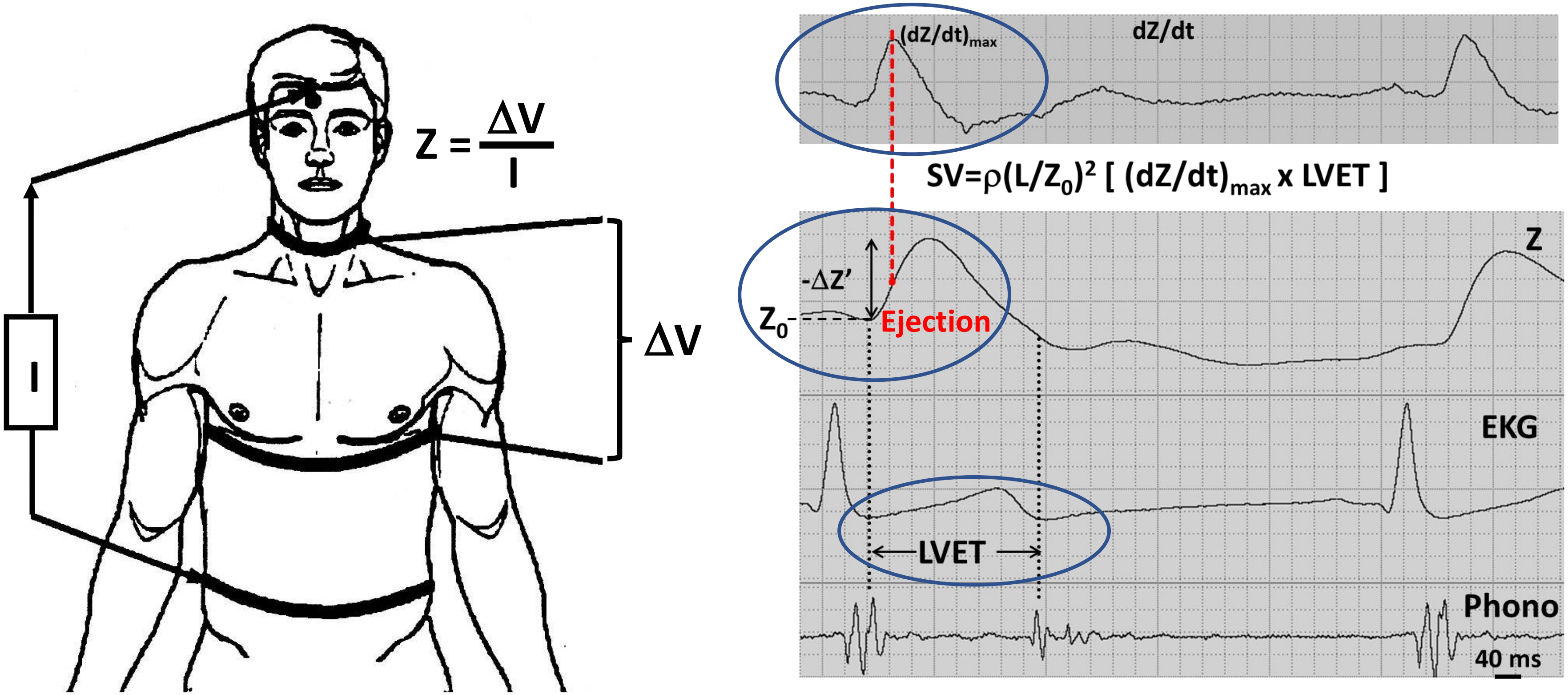
Afterload Preload

$$IC_{time} = \frac{P_D - LVEDP}{\Delta P/dt}$$

Contractility



Transthoracic Impedance Cardiography (TIC)



1. LV ejection into the aorta causes impedance (Z) of the thorax to decrease
2. Measurement of maximum rate of change of Z together with LVET allows for an estimation of stroke volume (SV) when combined with height of patient (L) and the density of the blood (ρ)
3. Method is useful for continuous monitoring of changes in SV and hence CO
4. Usually simultaneously records EKG and Phono

Electrophysiology & Electrocardiography Interactive Review MCQs

Bill is a 50-year-old male who is taking a medicine that increases sympathetic impulses to his heart. Which one of the following is the most likely effect?

A. Increased dromotropy and decreased inotropy

B. Increased chronotropy and decreased dromotropy

C. Increased inotropy and decreased lusitropy

D. Increased lusitropy and increased dromotropy

E. Decreased lusitropy and Increased inotropy

Which statement is correct regarding ventricular depolarization or repolarization?

A. The first regions that depolarize are the last to repolarize

B. The left atrium begins to depolarize slightly after the action potential reaches the AV node

C. Regions that are the first to repolarize tend to have shorter action potential durations (APD)

D. Concordance between the QRS and T wave is when they change in the opposite directions

E. Depolarization of the septum accounts for the S part of the QRS complex

Jane undergoes an exploratory procedure in an electrophysiology lab to investigate recurrent arrythmias. A result of the investigation demonstrates frequent ectopic impulses located in the left atria were a cause of her now diagnosed reentrant arrhythmias. **Which of the following favors such reentrant arrythmias in the left atrium?**

A. Increased action potential (AP) conduction speed

B. Increased size of the left atrium

C. Increased AP phase 0 rate of rise

D. Reduced AP duration (APD)

E. Increased AP amplitude

Bill's heart has only one problem. It has a completely nonfunctional SA node and is being paced by normal AV node activity. **For this condition, what is most likely to be observed?**

A. A widened QRS complex

B. Absence of any P-waves

C. Reduced conduction speed in the bundle branches

D. Presence of negative P-waves

E. A slightly greater than normal heart rate

Mary goes for her annual physical and receives a 12-lead electrocardiogram as part of the exam. Based on this EKG it is determined that she has left axis deviation with a mean electrical axis (MEA) which is at minus 90 degrees. **Which of the following EKG leads would have the least R-wave amplitude?**

A. I

B. II

C. III

D. aVR

E. Avl

Five male patients between the ages of 55 to 60 each received an EKG at the same office after complaining of strange feelings in their chest. Lead II for each of the patients is shown in the accompanying figure. **One of the men was diagnosed with atrial fibrillation (aFib). Which tracing most likely belongs to that patient?**

A. A

B. B

C. C

D. D

E. E

Five male patients between the ages of 55 to 60 each received an EKG at the same office after complaining of strange feelings in their chest. Lead II for each of the patients is shown in the accompanying figure. **One of the men was diagnosed as having one atrial retrograde ectopic impulse. Which tracing most likely belongs to that patient?**

A. A

B. B

C. C

D. D

E. E

End CV Physiology Lecture 7