Shock-induced termination of cardiac arrhythmias

Baltazar Chavez-Diaz; Sarah Schwenck; Weide Wang;
Jinglei Zhang; Chen Jiang
Mentor: Williams Katie

Presentation Overview

- Background
- Model
- Equations & Parameters
- Analysis
- Conclusion

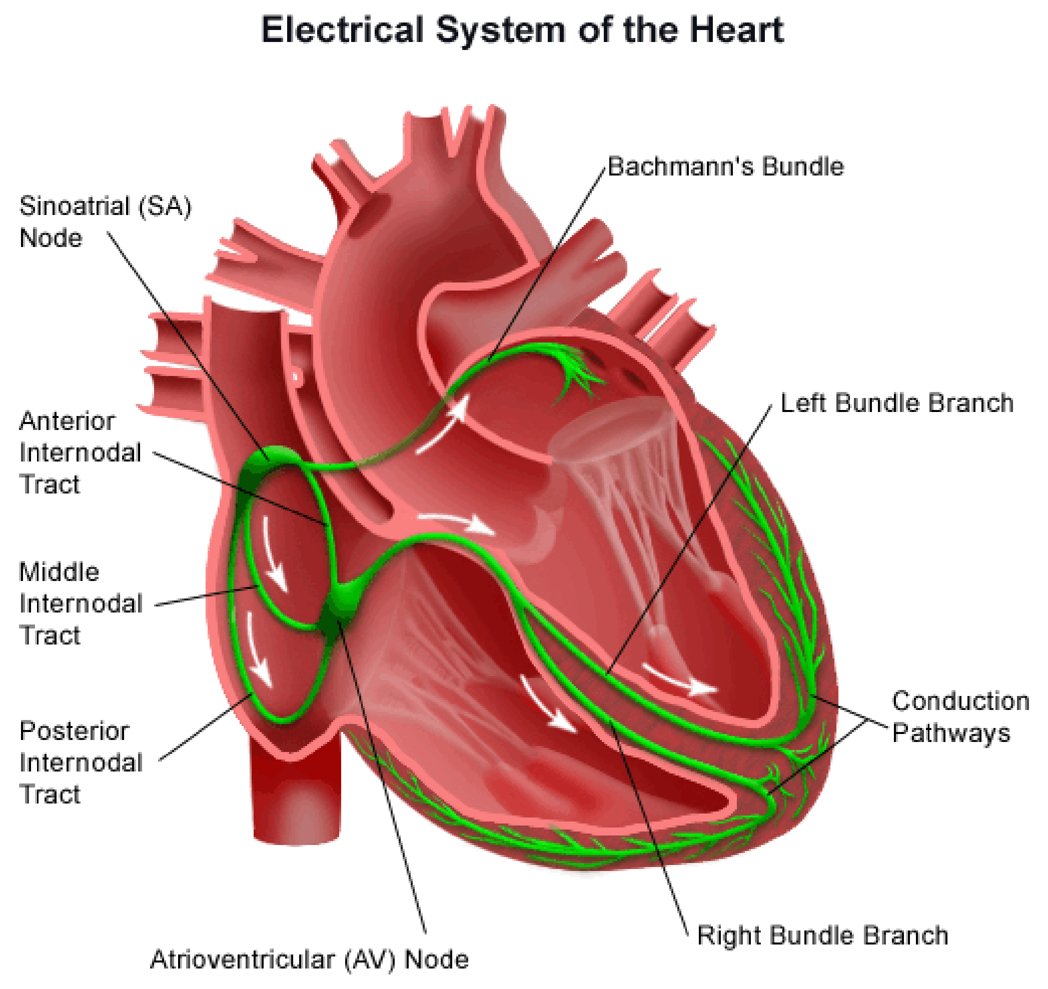
Cardiac Arrhythmias

Cardiac dysrhythmia or **irregular heartbeat**

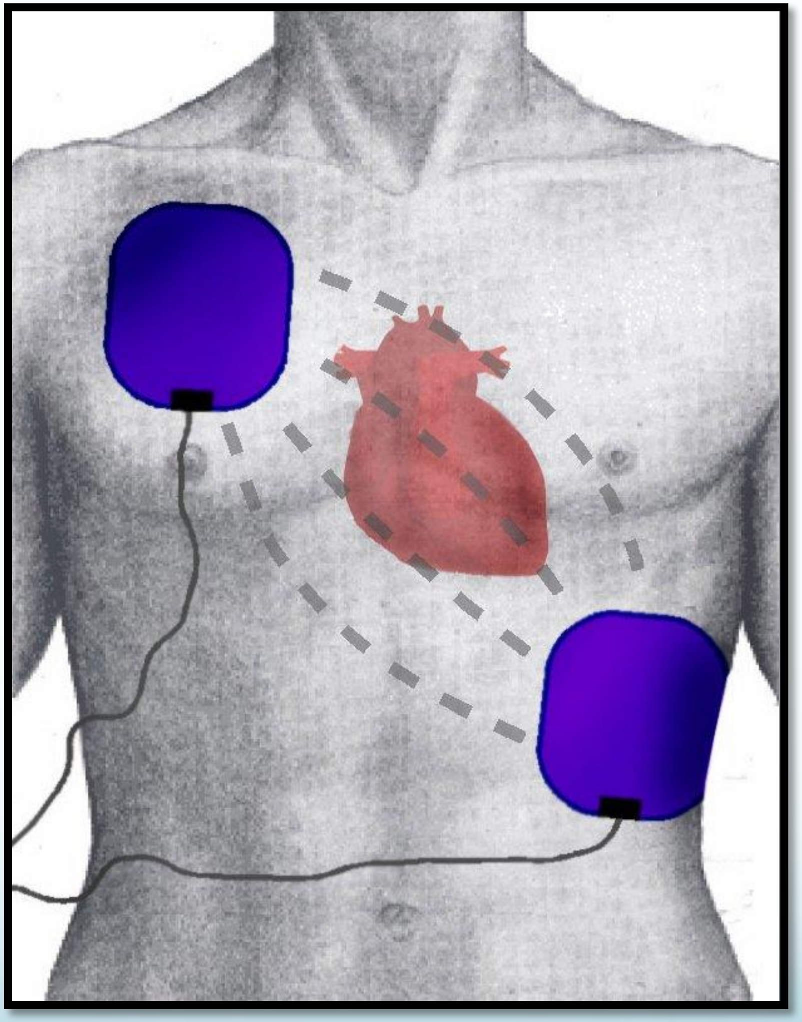
Irregular **Electrical** activity of the heart

Regular or irregular

Cardiac Arrhythmias



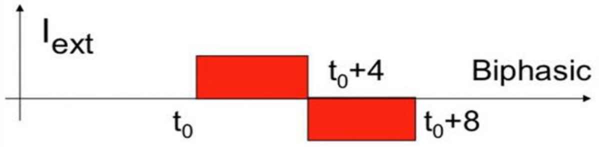
Defibrillators



Defibrillators

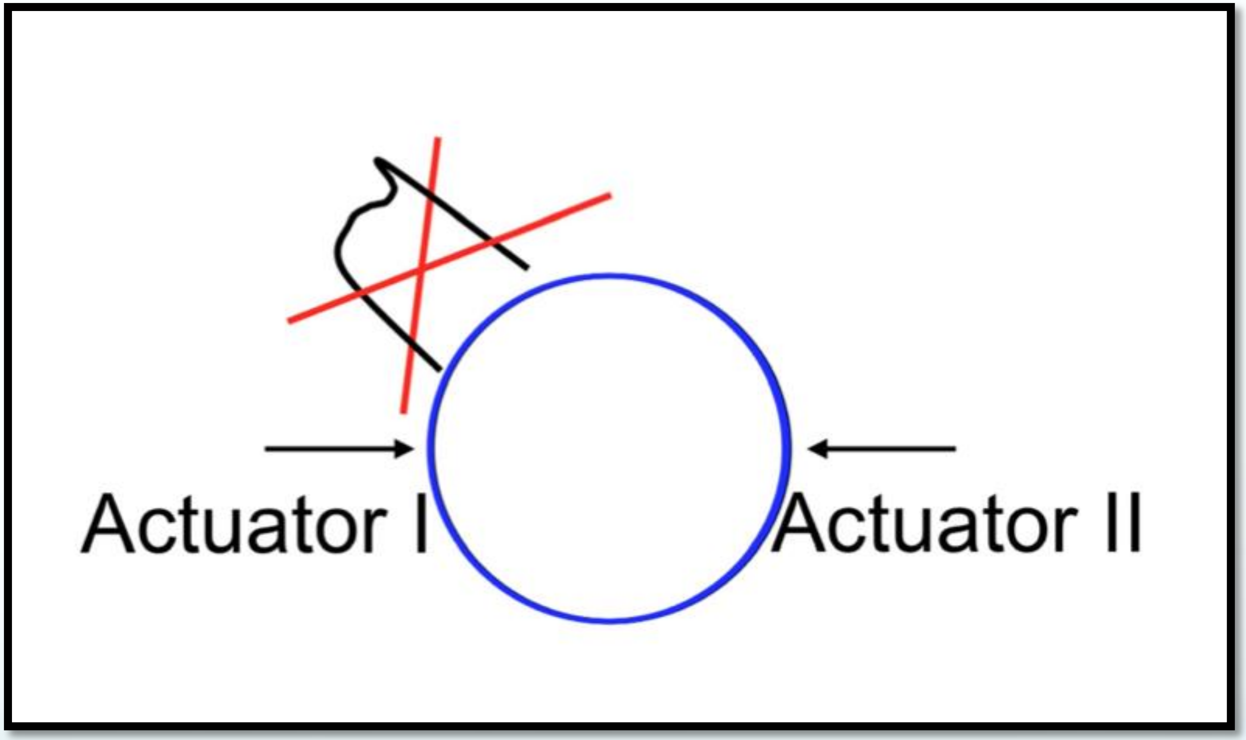
Monophasic

Symmetric Biphasic



Asymmetric Biphasic

Model



Beeler-Reuter Equation

Describe the electrical activity of cardiac myocytes

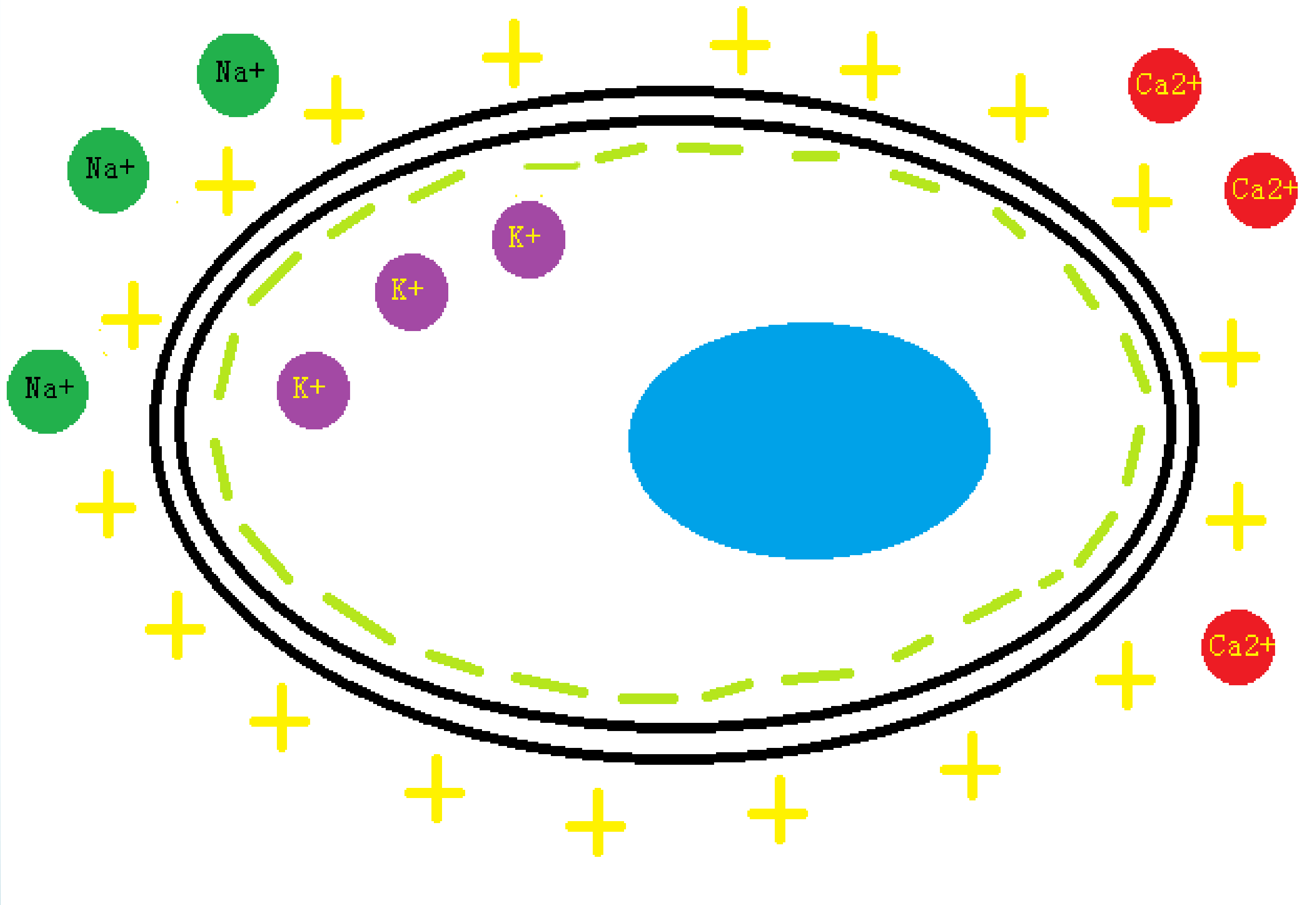
Beeler-Reuter Equation

- $\frac{\partial V_m}{\partial t} = -\frac{I_{BR}+I_{ep}+I_{fu}}{C_m} + \nabla \cdot (D_g \cdot \nabla V_m) + \nabla \cdot (D_g \cdot \nabla \varphi_e)$

- V_m : membrane potential
- φ_e : extra-cellular potential
- D_g : intra-cellular diffusion of the electrical potential
- C_m : Capacitance per surface area of the myocyte membrane

- $I_{BR} = I_k + I_x + I_{Na} + I_s$

$$I_{BR} = I_k + I_x + I_{Na} + I_s$$



- $\frac{\partial V_m}{\partial t} = -\frac{I_{BR}+I_{ep}+I_{fu}}{C_m} + \nabla \cdot \left(D_g \cdot \nabla V_m\right) + \nabla \cdot \left(D_g \cdot \nabla \varphi_e\right)$

Electroporation phonomenon

I_{ep}

- When the strength of the applied electric field exceeds a few V/cm, reversible pores are created in the myocyte membrane that allow for ion flow across the membrane.
- As a result, the membrane potential Vm saturates and does not reach unphysiological values for either depolarization or hyperpolarization.

- I_{fu} is an additional current that is needed to account for the possible anode break stimulation of the tissue.

Numerical techniques

L= 6.7 cm

dx = 0.025 cm

- Spatial discretization

dt=0.001ms

- During the shock and for the subsequent 10ms and then the time step is changed back to dt=0.01ms for the rest of the simulation.

Parameter influencing the defibrillation outcome

1) The shock waveform
2) The shock duration
3) The shock energy
4) Shock timing
5) Dynamical state at the time of the shock
6) Heterogeneity of the cardiac tissue
7) System size

Simulations

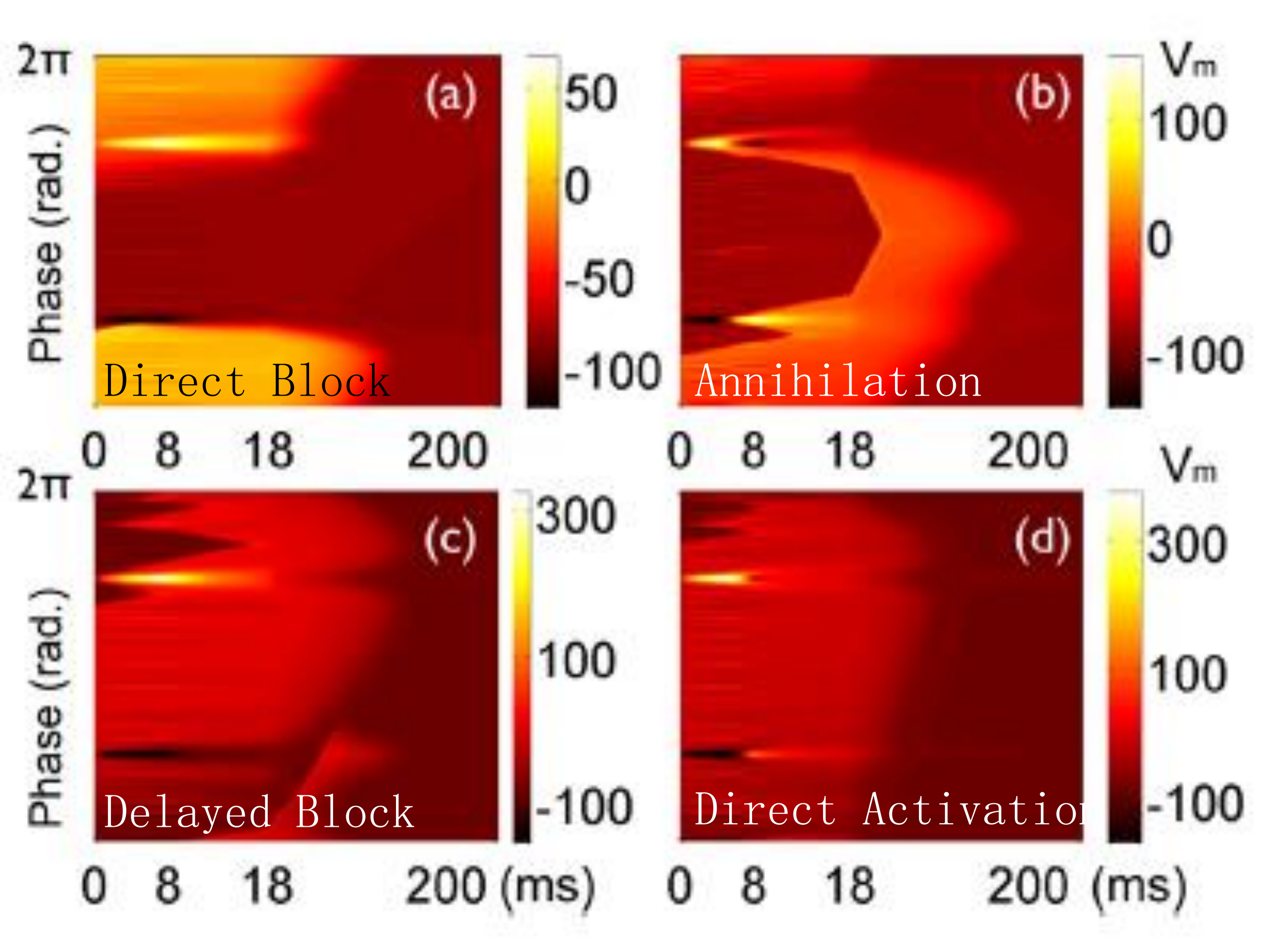
Classification using Artificial Neural Networks (ANN)

- Direct Block, Annihilation, Delayed Block, and Direct Activation

Dose response curves

Analysis of shock timing and size of the action potential

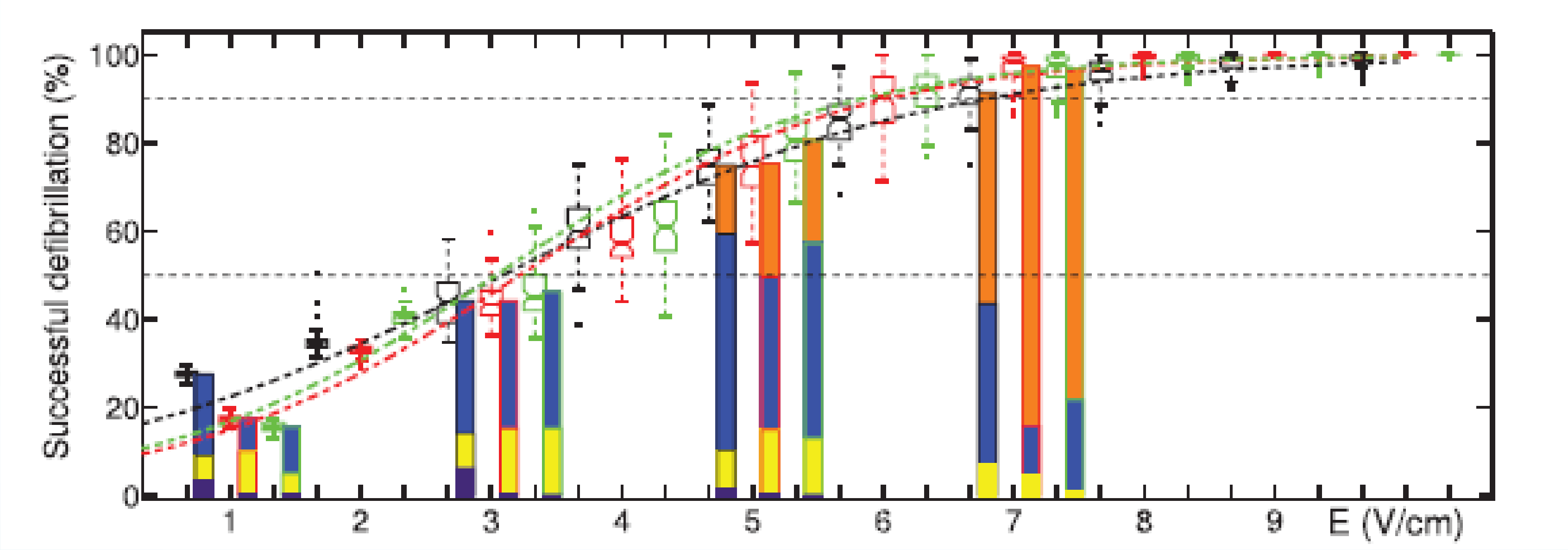
Mechanism Classification



Compute the location and direction of waveforms present

Use this as input for ANN

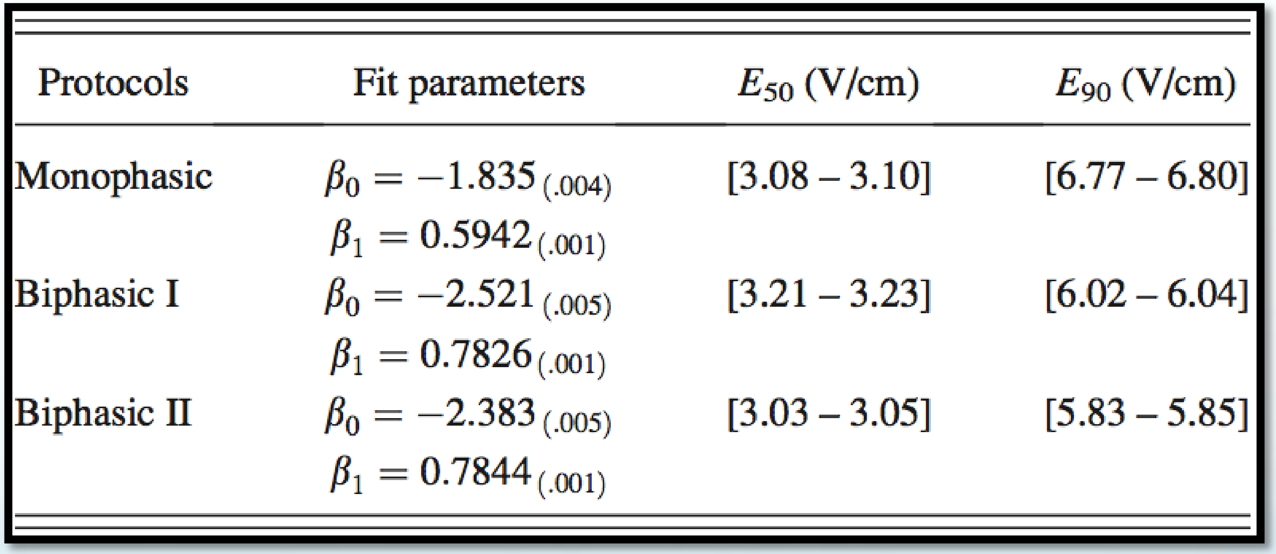
Mechanism abundance changes with shock energy



- Direct Block mechanism only present in monophasic
- Direct Activation mechanism more prominent at higher energies

Dose Response Curves

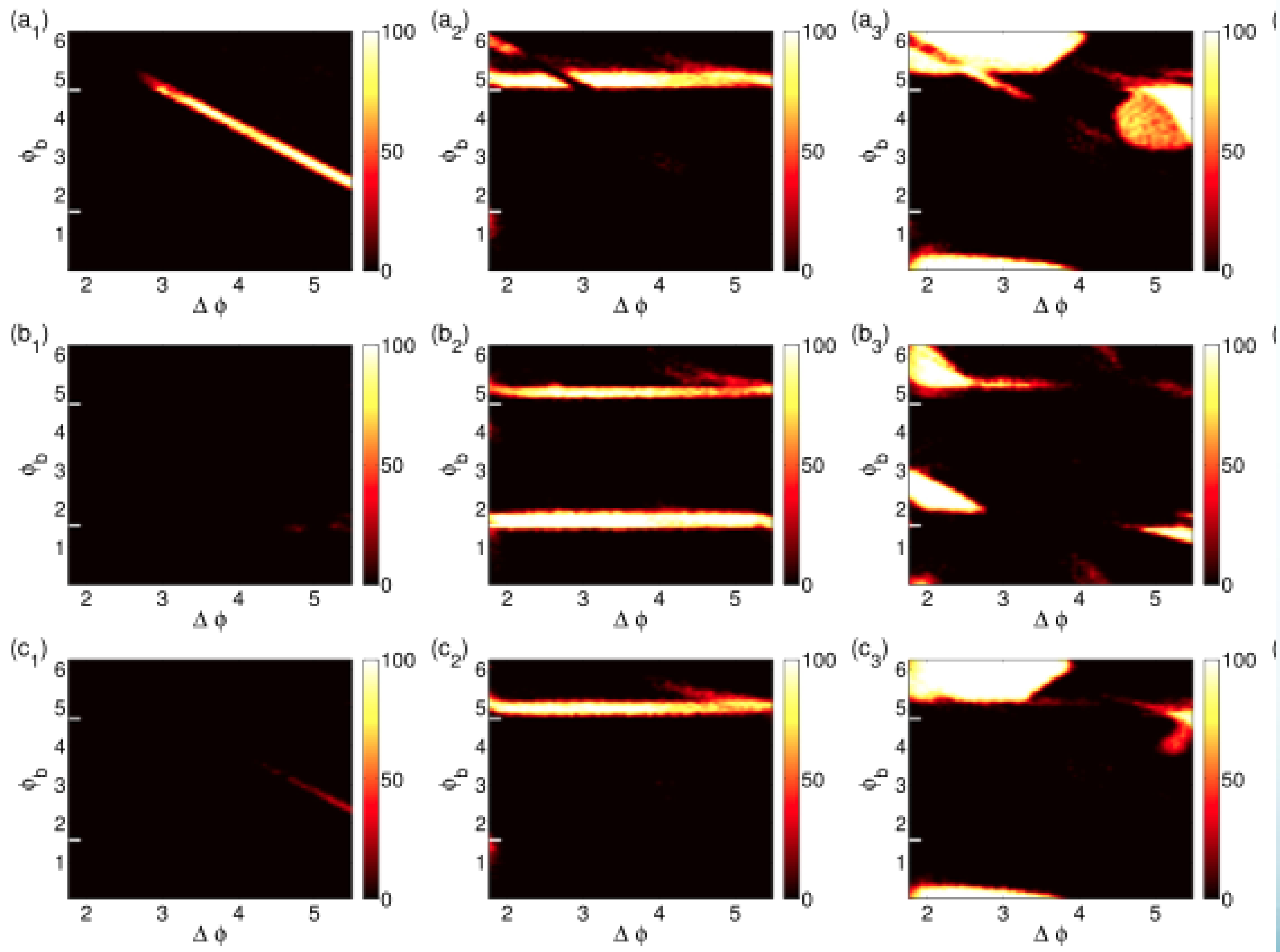
- $\log\left(\frac{p}{1-p}\right) = \boldsymbol{\beta}_0 + \boldsymbol{\beta}_1 \mathrm{E}$
- p is probability of successful defibrillation



Protocols	Fit parameters	E_{50} (V/cm)	E_{90} (V/cm)
Monophasic	$\beta_0 = -1.835_{(.004)}$ $\beta_1 = 0.5942_{(.001)}$	[3.08 – 3.10]	[6.77 – 6.80]
Biphasic I	$\beta_0 = -2.521_{(.005)}$ $\beta_1 = 0.7826_{(.001)}$	[3.21 – 3.23]	[6.02 – 6.04]
Biphasic II	$\beta_0 = -2.383_{(.005)}$ $\beta_1 = 0.7844_{(.001)}$	[3.03 – 3.05]	[5.83 – 5.85]

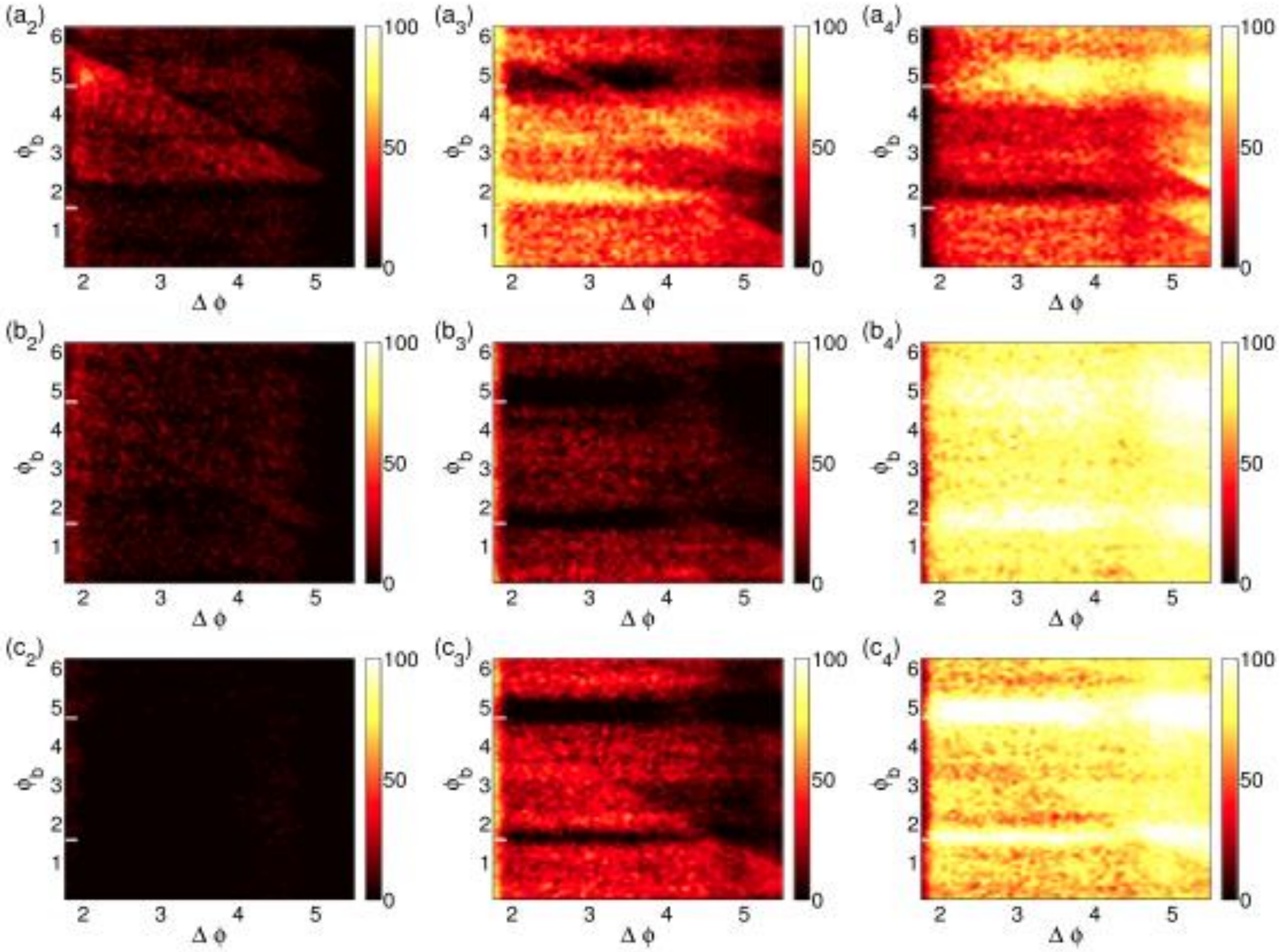
E = 1 V/cm

Column 1: DB　　Column 2: An　　Column 3: De



E = 7 V/cm

Column 1: An　　Column 2: De　　Column 3: DA



Protocol efficiency varies with shock energy

E (V/cm)	Monophasic	Symmetric Biphasic	Asymmetric Biphasic
1	27.50	17.33	15.50
2	34.48	33.10	40.65
3	43.93	43.38	45.13
4	59.93	56.93	60.78
5	75.10	74.75	80.35
6	85.23	90.43	92.13
7	92.50	98.53	97.88
8	96.58	99.90	99.78
9	98.75	100	100
10	99.68	100	100

Conclusion

- Direct block only happens at low energy
- Direct activation predominates at high energy
- Monophasic is the most efficient at low energy
- Asymmetric biphasic is the most efficient otherwise

Conclusion

High E → 90% success

- The analysis of the numerical data shows that when the energy is high (which E is 7V/cm here) all of these three protocols will achieve 90% success

Efficiency

$$Efficiency_{(biphasic\_II)} > Efficiency_{(biphasic\_I)} > Efficiency_{(monophasic)}$$

Future Research

Asymmetric Biphasic

- Shorter first-phase vs. Shorter second-phase

Shock Duration

- Change the shock duration to less than 8 ms

Questions