Electrical Stimulation of Excitable Tissue

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Electrophysiology and Bioelectricity
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Spherical Cell Model

- Simplifying assumptions:
  - $R = \frac{R_m}{A}$
  - $C = \frac{C_m}{A}$
Spherical Cell Circuit Model

Can treat it as a simple RC network

\[ v_m = I_o R (1 - e^{-t/\tau}) \]

Where \( \tau = RC \),
Threshold Voltage and Time

\[ V_T = S(1 - e^{-T/\tau}) \]

T is the time needed to reach threshold, \( V_T \) is the threshold voltage, and \( S = I_0 R \)

Solving for T...

\[ T = \tau \ln \left( \frac{S}{S - V_T} \right) \]
Weiss-Lapicque Equation

\[ V_T = S(1 - e^{-T/\tau}) \]

May be rearranged to

\[ S = \frac{V_T}{(1 - e^{-T/\tau})} \]

Dividing by both sides by R

\[ I_{th} = \frac{I_R}{(1 - e^{-T/\tau})} \]

\( I_R \) is defined as the rheobase. \( I_{th} \) is the minimum threshold to achieve threshold with a stimulation of duration \( T \).
Strength-Duration Curves

Chronaxie

2x Rheobase

Rheobase
Chronaxie

The pulse duration when the stimulation strength is twice rheobase is the chronaxie ($T_c$).

$$V_T = 2V_T (1 - e^{-T_c/\tau})$$

$$e^{-T_c/\tau} = \frac{1}{2}$$

$$T_c = \tau \ln(2) = 0.693 \tau$$
Application of Weiss-Lapicque Equation

Can the Direct Cardiac Effects of the Electric Pulses Generated by the TASER X26 Cause Immediate or Delayed Sudden Cardiac Arrest in Normal Adults?

Raymond E. Ideker, MD, PhD,*†‡ and Derek J. Dosdall, PhD‡
Passive Membrane Response

![Graph showing stimulus and transmembrane potential over time.]

- **Stimulus**: A constant value across the time period.
- **Transmembrane Potential**: Shows a rise to 63% at 3.6 ms, then returns to baseline after 80 ms.
Blair’s Equation

\[ I_T(d) = \frac{I_r}{1 - e^{-d/\tau}} \]

Where \( I_T(d) \) = Threshold current for given pulse duration
\( I_r \)=rheobase (63.7 ms)
\( d \)=pulse duration (0.1, 2.5, and 34.7 ms)
\( \tau \)= tissue time constant (3.6 ms)

So ...

\( I_T(d) \) = 2.3, 0.13, and 0.06 A
## External Pacing Threshold

<table>
<thead>
<tr>
<th>Study</th>
<th>Pulse Width</th>
<th>Threshold</th>
<th>Current</th>
<th>Std Dev</th>
<th>N</th>
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<tbody>
<tr>
<td>Luck et al.</td>
<td>40</td>
<td>64±14 (range 40-80)</td>
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<tr>
<td>Prochaczek et al.</td>
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<td>59±20 (range 28-80)</td>
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<td>Altamura et al.</td>
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<td>Kelly et al.</td>
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<td>60±3</td>
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<td>Falk and Battinelli</td>
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<td>73±6 (SEM)</td>
<td>73</td>
<td>33.9411255</td>
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<tr>
<td>Falk and Batinelli</td>
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<td>74±7 (SEM)</td>
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<td>39.5979797</td>
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<tr>
<td>Kemnitz et al.</td>
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<td>57±20 (range 30-90)</td>
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<td>Falk and Ngai</td>
<td>20</td>
<td>Ammeter 77.3±16.4</td>
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<tr>
<td>McEneaney et al.</td>
<td>40</td>
<td>72.9±22</td>
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<tr>
<td>Prochaczek et al.</td>
<td>30</td>
<td>59.7±11.6</td>
<td>59.7</td>
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<tr>
<td>Estes et al.</td>
<td>40</td>
<td>68±15</td>
<td>68</td>
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</tbody>
</table>

Since the pulse width is $>>\tau$, the external pacing threshold $\approx I_r$.
The taser pulse may be approximated by a 1 A, 100 \( \mu \text{s} \) square wave.
Placement of Pacing Leads

Assume that the TASER darts were placed at the optimal location for stimulation
Motor Neuron vs Cardiac Cell Response

$\tau = 3.6$ ms for cardiac tissue and $\tau = 0.24$ ms for motor neurons, so short pulses have a much larger effect on motor neurons.
Pulses delivered temporally close together would have an additive effect for cardiac tissue

But TASER pulses are delivered approximately 53 ms apart and have no cumulative cardiac effect
Paper Conclusions

TASER pulses have a strong effect on motor neurons but have a very low probability of stimulating cardiac tissue even with electrodes placed at optimal locations.