Clinical Neurophysiology

2013

Peter Trillenberg
Dept. of Neurology
# Basic and clinical Neurophysiology

<table>
<thead>
<tr>
<th>Basic neurophysiology</th>
<th>Clinical neurophysiology</th>
</tr>
</thead>
<tbody>
<tr>
<td>Identify mechanisms that make the nervous system work</td>
<td>Diagnose disease in patients</td>
</tr>
<tr>
<td>Molecules, cells, groups of cells, functional systems</td>
<td>Correlates of functions of the intact human body</td>
</tr>
<tr>
<td>Invasive, time consuming, small number of „subjects“ studied</td>
<td>Reliable, fast, cheap, benefit justifies the risk</td>
</tr>
</tbody>
</table>
focus of neurophysiology

molecules

cells

systems

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parts of a nerve cell

- dendrites
- cell body
- axon
- synapse

summation of input

metabolism

propagation of the signal

transmission of the signal
functions in nerve cells

<table>
<thead>
<tr>
<th></th>
<th>chemical</th>
<th>electrical</th>
</tr>
</thead>
<tbody>
<tr>
<td>reception of information</td>
<td>●</td>
<td>●</td>
</tr>
<tr>
<td>calculation</td>
<td></td>
<td>●</td>
</tr>
<tr>
<td>signal transport</td>
<td></td>
<td>●</td>
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<tr>
<td>signal transmission</td>
<td>●</td>
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</tr>
</tbody>
</table>
biological membranes

- lipid bilayer (glycerole ester)
  - electrical isolation
  - chemical isolation

- membrane proteine
  - signal transduction
  - mechanical stability
  - immune mechanisms
  - transport

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electrical phenomena in nerve cells

1st step: resting state of a membrane patch: Why do nerve cells have a resting potential?

2nd step: action potential of a membrane patch: Why can nerve cells change their electrical properties?

3rd step: propagation of the action potential: Why does the action potential propagate along an axon?
excitable membranes: resting potential

starting situation
- concentration difference between intracellular and extracellular
- conduction across membrane only for kations

chemical gradient

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Excitable membranes: resting potential

Chemical gradient

Ionic current vs. time

Concentration vs. time

Charge vs. time

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Excitable membranes: resting potential

Equilibrium:
- zero current
- positive charges on the outside

\[ V_{Na} = \frac{RT}{zF} \ln \left( \frac{c_{IZR}}{c_{EZR}} \right) \]

(Nernst potential)
excitable membranes: resting potential

starting situation
- concentration difference for two varieties of kations
- different conductivities for kations
excitable membranes: resting potential

chemical gradient

ionic current

concentration

charge

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excitable membranes: resting potential

„equilibrium“
- more diffusion of the ions with larger conductivity
- outside charged positively
- equal currents by both kations
- potential across the membrane depends on conductivities
Excitable membranes as a weapon

Electrophorus electricus
Electrical organs with „electroplaques“ (adapted from muscle cells)
500 V, 2 A by using membrane potentials in a serial circuit
Excitable membranes: resting potential

“equilibrium“
- flux „blue in“ balances „red out“
- in the long run breakdown of concentration differences
excitable membranes: resting potential

„equilibrium“
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electrical phenomena in nerve cells

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excitable membranes: action potential

- depolarisation
- hyperpolarisation

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Excitable membranes: action potential

Starting situation:
- K conductivity and Na conductivity small ($K^+ > Na^+$)
excitable membranes: action potential

1st step in the action potential:
- increase in Na conductivity
- reversal in the membrane potential: „depolarisation“
excitable membranes: action potential

2nd step in the action potential:
- increase in the K conductivity
- membrane potential returns to baseline: "repolarisation"
excitable membranes: action potential

3rd step in the action potential:
- Na channels inactivated
- membrane potential below resting potential: „hyperpolarisation“
Excitable membranes: voltage gated sodium channels

3 states:
- open
- closed
- inactivated

Transition between states with voltage dependent rates

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excitable membranes: voltage gated sodium channels

resting potential

(open) ➔ (inactivated)

depolarized

(open) ➔ (inactivated)

transition to ☯:
triggers chain reaction

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Excitable membranes: voltage gated sodium channels

State of channels influences membrane potential

Membrane potential influences state of channel
→ excitable membranes: action potential

Trigger for the action potential:
- abrupt opening of sodium channels
Simplified version of the Hodgkin-Huxley equations

\[ C \frac{dV}{dt} = g_{Na} M(V)^3 (1 - R)(V - E_{Na}) + g_K R^4 (V - E_K) - g_{\text{leak}} (V - E_{\text{leak}}) + I \]

\[ \frac{dR}{dt} = \frac{1}{\tau_R(V)} (- R + G(V)) \]

\[ M(V) = \frac{\alpha}{\alpha + \beta}; \alpha = -0.1 \cdot \exp\left(\frac{V + 45}{10}\right) - 1 \]

\[ G(V) = \frac{S \cdot (N + S \cdot (1 - H))}{1 + S^2}; S = 1.2714 \]

\[ \tau_R(V) = 1 + 5 \cdot \exp\left(-\frac{(V + 60)^2}{55^2}\right) \]

\[ N(V) = \frac{\alpha}{\alpha + \beta}; \alpha = -\frac{V + 60}{\exp\left(-\frac{V + 60}{10}\right) - 1} \]

\[ H(V) = \frac{\alpha}{\alpha + \beta}; \alpha = 0.07 \cdot \exp\left(-\frac{V + 70}{20}\right); \beta = \frac{1}{\exp\left(-\frac{V + 40}{10}\right) + 1} \]

RINZEL J (1985) EXCITATION DYNAMICS - INSIGHTS FROM SIMPLIFIED MEMBRANE MODELS. FEDERATION PROCEEDINGS 44: 2944-2946

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Phase plot of Rinzel system

I = 7.095 µA

I = 10 µA

Schwelle: 7.09857705

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excitable membranes: voltage gated sodium channels

Tetrodotoxin: blocks sodium channels
high concentration in Fugu
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propagation of the action potential

Depolarized membrane patch

axon

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propagation of the action potential

depolarisation to threshold

Sodium channels inactivated

axon
propagation of the action potential

Concentration of the current at Ranvier nodes
Fortgeleitetes Aktionspotential

Intracellular recording

Surface recording

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sensory neurography

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sensory neurography

Latenz: 2.8 ms; d=14 cm
NLG = ?

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Suggested reading