12 YEARS LATER

Andrea Zangari, Davide Micheli, Roberta Galeazzi & Antonio Tozzi,

Node of Ranvier as an Array of Bio-Nanoantennas for Infrared Communication in Nerve Tissue // **Scientific Repots. V.8 Article number: 539 (2018)**

Electromagnetic radiation, in the visible and infrared spectrum, is increasingly being investigated for its possible role in the most evolved brain capabilities. Beside experimental evidence of electromagnetic cellular interactions, the possibility of light propagation in the axon has been recently demonstrated using computational modelling, although an explanation of its source is still not completely understood. We studied electromagnetic radiation onset and propagation at optical frequencies in myelinated axons, under the assumption that ion channel currents in the node of Ranvier behave like an array of nanoantennas emitting in the wavelength range from 300 to 2500 nm. Our results suggest that the wavelengths below 1600 nm are most likely to propagate throughout myelinated segments. Therefore, a broad wavelength window exists where both generation and propagation could happen, which in turn raises the possibility that such a radiation may play some role in neurotransmission.

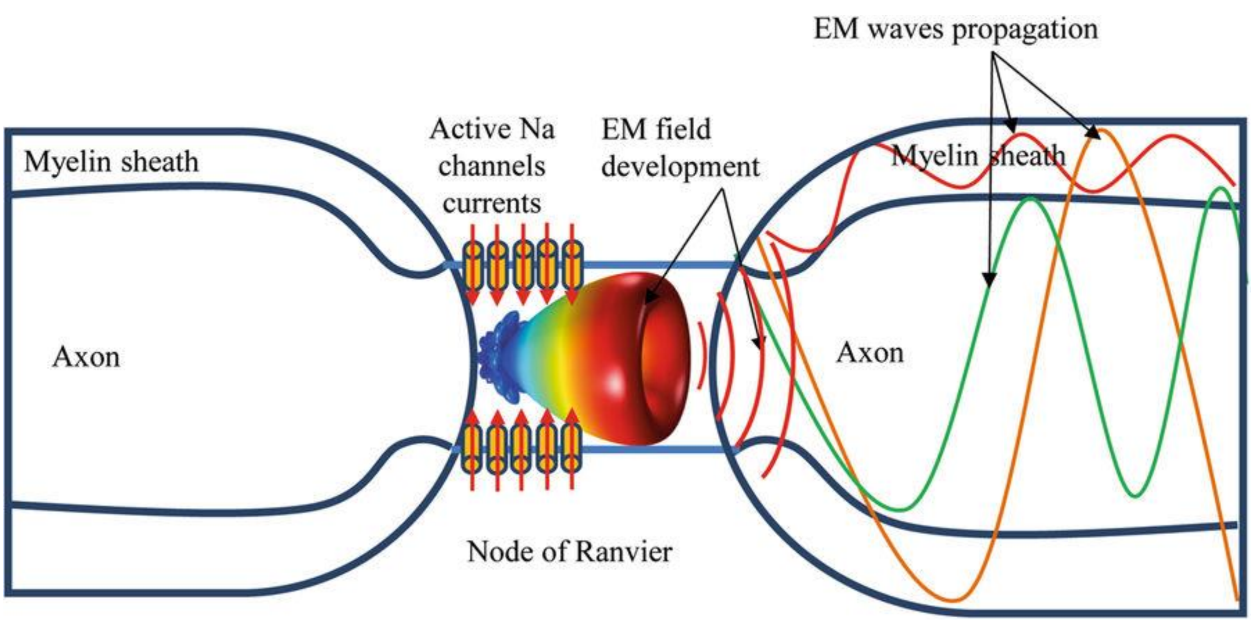

Fig 1. Schematic representation of ion channels in a Node of Ranvier behaving as nanoantenna array generating EM radiation.

A.S. Holmanskiy

Modeling of brain physics (in Russian) // Mathematical morphology. Electronic mathematical and medico-biological journal. T. 5. V. 4. 2006.
http://sgma.alpha-design.ru/MMORPH/N-12-html/holmansky-3/holmansky-3.htm
http://technic.itizdat.ru/docs/aholy/FIL13586744010N536872001/1

2.2. Electromagnetism of the neuron

It is obvious that EMP plays an essential role in the mechanisms of generation and action of electromagnetic fields of electromagnetic nature in the human nervous system. At the heart of its communicative and signaling functions lies the ability of nerve cells to generate and conduct electrical impulses. Electrophysics and metabolism of the nervous system and neurons are examined using ECG, EEG, MEG, NMR and positron emission tomography (PET) methods, thermoencephaloscopy, psychopharmacology and direct probing of nerve cells by microelectrodes. Quantum magnetometers (SQUID), in principle, allow one to register the magnetic field of an individual neuron [10, 11]. The phenomena of EMR and resonance, apparently, underlie the mechanism of sensitivity of the nervous system to direct effects of external EM radiation of various ranges. The presence in the nervous system of LC-structures, in principle, allows the "adjustment" of the sensory elements of the nervous system to the frequencies of both internal and external biogenic radiations by the principle of heterodyne coupling.

To explain the electrical properties of the membrane, an equivalent circuit is used, in which the conducting channels for various ions are modeled by the source of the EMF and the ohmic resistance (R), and the insulating properties of the membrane are the capacitance (Fig. 2).

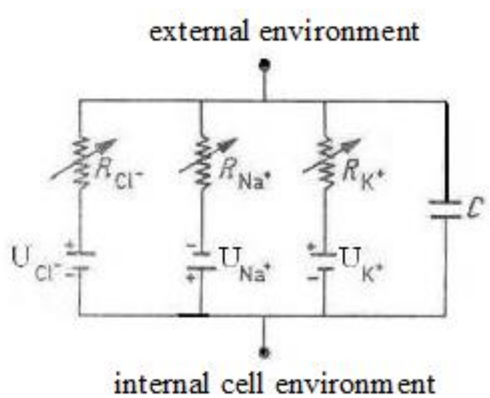

Figure 2. Equivalent electric model of the nerve membrane: the batteries create a total membrane potential U, ion conductivity is denoted by resistances R, capacitance of the membrane is capacitor C [12].

The parallel connection of several contours, shown in Fig. 2, simulates the neuron membrane [12]. However, for the neuron model of the central nervous system, which has a myelin sheath, the capacitive characteristics of the membrane are not sufficient. Indeed, in the spiral structure of myelin there are regular channels (notches) (Fig. 3), which, in the context of the equivalent electric model of the membrane (Fig. 2), can play the role of local inductance coils. The number of notches on one myelin fiber segment, the larger the thicker axon cylinder [13].

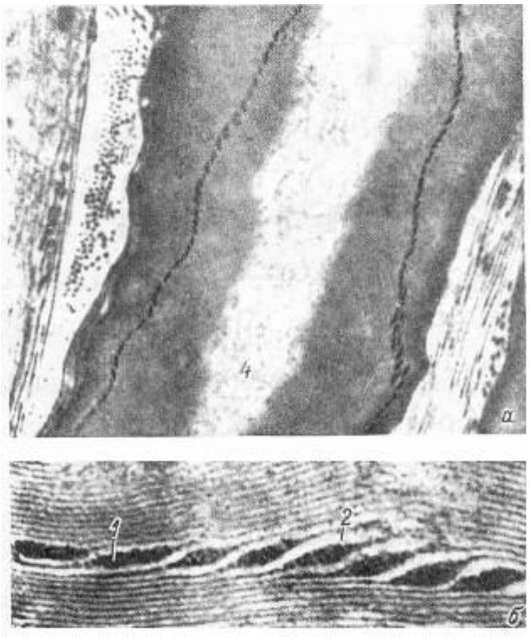

Figure 3. Ultrastructure of the myelin membrane of the nerve. a is a general view of the notch; b - enlarged image of notch [13].

The marginal structure of the myelin sheaths in the intercept region of Ranvier forms coils of spirals of paranodal loops of about 1 μm in length, communicating with the axoplasm through special windows. If these structures are regarded as inductors (Fig. 5-7), they will play an important role in the saltatory mechanism of axon conduction.

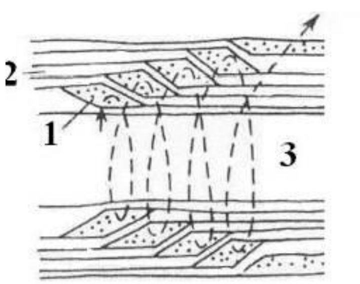

Fig. 4. Diagram of the cytoplasmic canal (incision) (1) in the myelin sheath (2) of the axon. 3 - axoplasm [13].

Differences in the electrodynamic properties of the axoplasm, membrane, and intercellular fluid, due to the difference in their ionic-molecular composition and structure, must leave their imprint on the mechanism of PD generation. The stimulus that starts the charge exchange of the membrane can be both physical and chemical, and the redistribution of charges can in one way or another balance the transfer of ions through the membrane and their adsorption on its surfaces [14]. With ionic currents of charge exchange of the surface of the axon membrane, impulse displacement currents will be associated in the paranodal loops and in the scroll channels of the notches, which allows them to be likened to magnetic dipoles [9]. The kinetics of ion currents and displacement currents in the axon, membrane, and paranodal loops of the myelin sheath correlates with the kinetics of growth and subsequent relaxation of the membrane potential. Since the phase of the PD growth lasts about 0.1 - 0.2 ms, and the relaxation time of the membrane potential is of the order of 1 ms [15], then the displacement impulse currents corresponding to the phase of increase will be an order of magnitude greater than the relaxation currents. Changing the charge on the inner side of the axon membrane in the Ranvier intercept region generates a polarization wave or bias current in the paranodal region of the myelin segment [16]. The magnitude of this perturbation will decay exponentially with distance [17], and the propagation velocity will not exceed the velocity of motion of the PD in the unmyelized nerve (of the order of 1 m / s). The presence of communication windows of the paranodal loops with axoplasm [16] ensures the transformation of the polarization wave into a circular bias current in the helices of the loops.

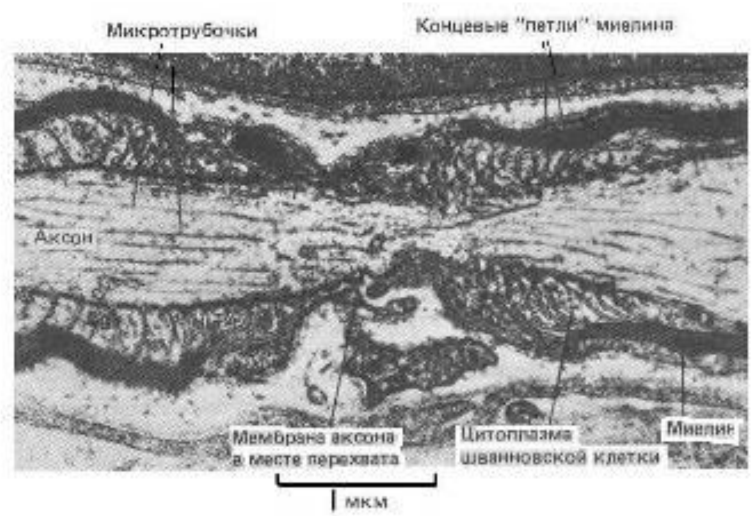

Figure 5. An electronic photograph of the interception of Ranvier, peripheral nerve [17].

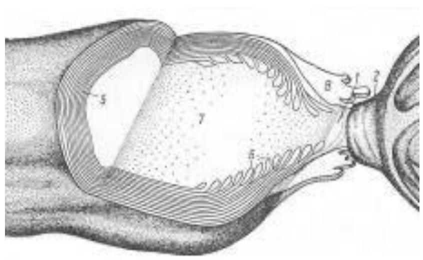

Figure 6. The scheme of the structure of the interception of Ranvier. 1 - intercept slot; 2 - the pulp cone; 5 - compact myelin; 6 - splitting of the main dense lines in the interception area; 7 - axial cylinder (axoplasma); 8 - cytoplasm of the Schwann cell [13].

Thus, the generation of PDs in the Ranvier interception is associated with the induction and emission of vortex EM quanta, whose metrics are simulated by EM vortices c) and c) in Fig. 1. It is possible that this is the main function of the end coils of the myelin sheaths and incision spirals. The direction of the vector of the flux density of the EM energy (the Poiting vector) will be determined by the sign of the spiral. This chirality factor of the neuron will ensure one-sided distribution of the EM-quantum, and therefore, PD on the myelinated nerve. Upon reaching the EM quantum with the velocity V (5) of the end coil of the myelin segment, it can play the role of a stimulus for the generation of PD in the next interception of Ranvier. In this model of the saltator conductivity of the neuron, the speed of the spike motion will be limited by the process of current excitation in the end coils, whose time is of the order of 10^{-6} s (1 μm: 1 m/s). At the same time, the average transfer rate of PD from one end of the myelin segment to the other at a length of about 100 μm and will determine the rate of the saltative mechanism of conductivity ~ 100 m / s.

Using the value of the potential difference corresponding to the PD of a typical neuron (U ~ 70 mV [15]), we estimate the amount of electrical energy that is expended in excitation of the PD in the Ranvier interception in the saltator mechanism of neuron conduction. To do this, imagine the interception in the form of a cylindrical capacitor, the lining of which is formed from the neuron membrane and the length is equal to the length of the interception (f). The change in the energy of the capacitor (W) can be estimated from the formula:

$$W = (U^2 C) / 2. \quad (8)$$

The value of C for a cylindrical capacitor with the distance between the plates (d) and the radius of the inner cylinder (R) under the condition d «R is equal to

$$C = (2\pi\varepsilon_o\varepsilon\ f) / [\ln (1 + d / R)] \approx (2\pi\varepsilon_o\varepsilon\ fR) / d$$

and the quantity

$$W = (U^2\ \pi\varepsilon_o\varepsilon\ fR) / d \quad (9)$$

We substitute in (9) such values for a nerve with R = 5 μm [17]: U ~ 0,07V; $\varepsilon o = 8.85\ 10^{-12}$ F / m; ε ~ 5; f ~ 10^{-7} m; d ~ 10^{-8} m, we obtain

$$W \sim 510^{-17} \text{ J or } 310^{7} \text{ J / mol.} \quad (10)$$

The same value of W is obtained if we substitute in C the value $C = 10^{-2}$ F / m^2 [17] for the same parameters of Ranvier intercept and U. The value (10) is comparable with the energy released during oxidation of ~ 10 glucose molecules and at the hydrolysis of ~ 10^3 ATP molecules.

It is known [12, 17] that during the hydrolysis of one ATP molecule, ~ 3 Na + ions pass through the membrane in exchange for two K^+ ions, and when the PD is excited, the flux density of Na^+ ions through the intercept membrane is J_{Na} ~ 410^3 ions / μm2. Then the number of Na^+ ions entering into the axon will be equal to J_{Na} (2πRf) ~ 10^4, it corresponds to ~ 310^3 ATP molecules, the total energy of which agrees in order of magnitude with (10). When ATP concentration in axoplasm of axon of squid is ~ 1 mmol per kg of H_2O [12], the total number of ATP molecules in the Ranvier interception cylinder (radius 5 μm and length 1 μm) will be ~ $4{,}10^7$ molecules. Consequently, the value of W is only 0.01% of the total energy resource of the Ranvier interception.

It is obvious that the energy of the EM quantum that plays the role of the stimulus of the PD generation in the Ranvier interception will be one, two orders of magnitude less than the value of W. For example, for the upper limit of the energy of the EM quantum one can take the energy of a photon with a wavelength of 600 nm ($4\ 10^{-19}$ J), which is sufficient to excite the signal in the retinal cell of the retina [15].

10. Kholodov Yu. A., et al. Magnetic fields of biological objects. M .: Nauka, 1987.
11. Risto Naatanen, Attention and function of the brain. Moscow State University. 1998
12. F.Huho Neurochemistry, Fundamentals and Principles. M. World 1990
13. Sotnikov O.S. Dynamics of the structure of a living neuron. Moscow: Nauka, 1982.
15. The Physiology of Man, ed. R. Schmidt, G. Tevs. 1- 3 tons, M., 1996
17. Alberts B. et al. Molecular biology of the cell. T 3. M., Mir, 1994

Kholmanskiy A. S., Minakhin A. A.

Interrelation of electrical oscillations of heart and brain

Vestnik SPbSU. Medicine, 2018, vol. 13, issue 2, pp.
The article was received on October 10, 2017.

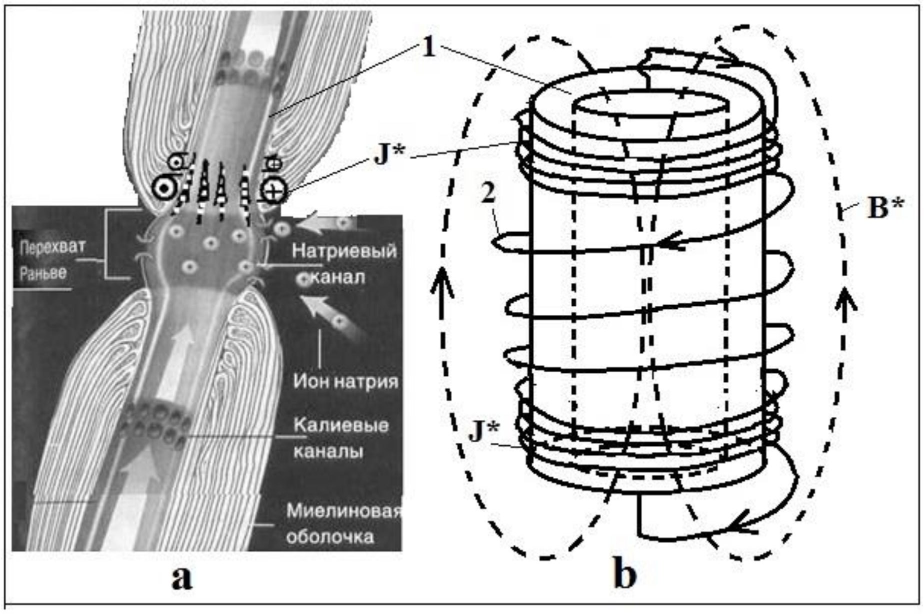

Fig. Electromagnetic model of the saltatory mechanism of nerve impulse transmission. The Ranvier intercept scheme from - a) and the myelin segment model - b). 1 - axon membrane, 2 - spiral gaps and incisions between myelin layers; J* is the displacement current, B* is the vortex magnetic field.