Characteristics of electrical biosignals

Biosignals can have a different physical nature, from the point of view of further processing, electrical biosignals occupy a prominent place. Active and passive properties of tissues at all levels of the organism's hierarchical structure are behind the emergence of electrical biosignals.

Electrical properties of tissues

Passive electrical properties

The passive electrical properties of a given environment tell how the given environment will behave in an electric field, i.e. what kind of conductor the given environment is actually. As an electrical conductor, tissue is a relatively complex environment. Ions serve as the charge carriers themselves, so Ohm's law in its simplest form does not apply. Furthermore, tissues are mainly divided by cell membranes and some other structures (e.g. skin) that have high electrical resistance. The passage of electric current can cause electrochemical changes, at higher intensity it can also cause spasms of blood vessels and at even higher thermal damage, so the passage of current modifies passive electrical properties.

The inhomogeneity of the passive electrical properties of e.g. the skin leads to the fact that when the current passes, the current density is significantly higher in the hair follicles and in the sweat glands (it is inaccurately said that the current flows through these structures).

The passive electrical properties when passing alternating current are also complex. Structures that functioned as insulators become capacitors with a non-negligible capacity. However, the simplest model of tissue impedance is only realistic for harmonic excitation, because ohmic resistance and capacitance also depend significantly on frequency.

Active electrical properties

Active electrical properties actually mean the ability of an organism to serve as a source of electrical voltage/current. A significant electrical voltage arises in the organism primarily as resting membrane potential of all cells, but action membrane potential is much more important for measurements in clinical practice.

Quantities used

The following physical quantities are used to characterize biosignals:

- **electric voltage U'** [V] – characterizes the potential energy of unevenly distributed charged particles
- **electric current I'** [A] – characterizes the flow of charged particles through a body
- **electrical resistance R** [Ω] – characterizes how easily a direct current flows through a specific body
- **electrical impedance Z** [Ω] – characterizes how easily direct current flows through a specific body

Usually, electrical voltage is measured as an active electrical quantity and electrical impedance as a passive electrical quantity.

Electric voltage contains information about the activity of the relevant organ made up of electrically excitable tissue. For example, information on the activity of electrically excitable cardiomyocytes is recorded as EKG, information on the activity of electrically excitable neurons is recorded as EEG, and information on the activity of electrically excitable uterine smooth muscle cells during childbirth is part of the recording from cardiotocograph.

Electrical impedance as a passive electrical property carries information about tissue structure. It is important to realize that impedance is a property of the body's structure and geometric arrangement. Impedance will thus affect changes in the volume of organs as well as changes in composition. Therefore, impedance can be used both to measure volume (plethysmography) and to measure composition (bioimpedance analysis)

Electrical events in the organism

Electrical events in the organism, which are responsible for the generation of electrical biosignals, take place on several levels.

Subcellular level

At the subcellular level, the uneven distribution of the electric charge in the cell is mainly manifested due to the existence of electrically charged structures with a relatively large molecular weight. If the tissue is placed in an electric field, a force proportional to their charge begins to act on these structures. It should be noted that for most molecules, the force of electric currents that do not cause damage is comparable to the force caused by thermodynamic collisions with surrounding molecules, and therefore, especially for large molecules, the charge movement is not easy and significant.

At the subcellular level, a hypothetical mechanism of generating electromagnetic waves can also be applied, as charges fixed on the cytoskeleton, for example, oscillate. However, the truth is that no sufficiently credible experimental or theoretical evidence has yet been presented for the existence of such a phenomenon.

Cellular level

At the cellular level, the membrane potential manifests itself mainly, the molecular essence of which is the uneven permeability of the membrane for charged particles. As a result, thermodynamic equilibrium is established with an uneven distribution of electric charge. The resting membrane potential is measurable in every living cell. Even the resting membrane potential is actively maintained because it also has its physiological functions. A special case is the action membrane potential, when the permeability of the membrane for some ions changes temporarily. Through this process, rapid signaling occurs between cells that are able to respond to changes in potential.

From the point of view of passive electrical properties, a more detailed analysis of tissue impedance shows that the cell is actually a conductive environment wrapped in an insulator, in which material charges are bound. This is one factor that causes the tissue to actually deviate from the idealization of the ideal resistor and capacitor model.

Tissue and Organ Level

From the point of view of active electrical properties, at the level of tissues and organs there is a summation or, on the contrary, a macroscopic disruption of the individual contributions of the electrical potentials of the cells. In general, the more the activity of the unit cells is synchronized, the higher the value of the voltage measured on the surface of the tissue or organ. For example, the resting EEG recording is relatively poorly synchronized and therefore has a smaller amplitude than the EEG recording during an epileptic seizure, the essence of which is the pathologically synchronized activity of a larger number of neurons.

From the point of view of passive electrical properties at this level, the electrical impedance is mainly influenced by the structure of the tissue. It is mainly about vascularization, the presence of fibrous septa and the construction and hydration of the intercellular mass.

Links

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Resources

- NAVRÁTIL, Leoš – ROSINA, Joseph, et al. *Medical Biophysics.* 1 (reprint 2013) edition. Grada Publishing, 2005. 524 pp. ISBN 978-80-247-1152-2.