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The Biophysical Modeling of the Human Tegument

Janos Vincze, Gabriella Vincze-Tiszay
Health Human International Environment Foundation, Budapest, Hungary
Email address: ndp@t-online.hu

Abstract— *Sensory organs are parts of our body, which collect and transmit information to the central nervous system about the outside world, and about the internal condition of our body. The body collects information by millions of microscopic structures, the so-called receptor cells. These can be found in almost all parts of the body, skin, muscle, joints, internal organs, in the walls of blood-vessels and in specialized organs such as the eye or the inner ear. There are numerous types of receptor cells in the skin. Some of them register mechanical stress or pressure, others the position and displacement of sensory hairs. Different stimulation cause different sensations, such as pain, tickling, hard or light pressure, heat or cold. The nerve fibres connected to the receptor transform stimuli above threshold into sequence of actions potentials. We modelling the action potential in the mathematical equation. Although our current knowledge regarding the mechanisms of pain development is incomplete, a number of pain-related phenomena have been discovered, which bear importance from both pathobiophysical and clinical aspects. Skin is an important receptive field, due to the numerous and various terminations of the cutaneous analyser which informs the nervous centres on the proprieties and phenomena that the body gets in contact with*.

Keywords— *human tegument, hand nail, action potential, pain reception*.

I. Introduction

The connection between the organism and the environment is made through the analysers, real information channels, which receive, lead and integrate the excitations in the environment as specific conscious sensations. The anatomical-physiological apparatus of sensations is called analyzer and it is made of three parts, tightly connected between them: the receiver or the analyser's peripheral segment, the afferent pathway which takes the excitation to the cerebral cortex and the cortical segment of the analyser. [1]

The peripheral segment – the receiver:

– is represented by specialized structures integrated in the sense organs;

– stimulated by the variation of an energy form and finally the action potential (nervous inflow) which propagates in the following segment;

– the receiver – it only performs a gross analysis.

The intermediary – leading segment is formed of:

– direct pathways – they are specific pathways, with a few synapses, through which the nervous impulses are lead rapidly and they are projected in the cortical areas, in specific areas;

– indirect pathways – nonspecific nervous pathways, with a lot of synapses and through which the nervous inflows are led slowly, in the cortical areas, where they project diffusely and non specifically.

The central segment is represented by two types of cortical areas:

– primary cortical area, where the fibres of the leading pathway are projected;

– secondary cortical area connected with the primary area.

The associative function does not have a specific area, but it is realized by the entire cerebral cortex. [2] Any excitation which reached the cortex can be associated with any activity of the organism. The entire cerebral cortex represents a reception surface. The perfecting of the function of the analysers is exemplified with those individuals which, after loosing the function of one or more analysers, reach a special development of the function of the integer analysers.

II. The Structure of the Tegument

The tegument (skin, cutis) is the membranous layer which covers the entire surface of the body, continuing in the natural orifices with the mucous layer of those cavities. Skin is the biggest organ of the human body, with a weight of 4–6 kg and a surface of 1,70–1,75 m^2, being made of three layers represented by epithelium (epidermis), conjunctive matrix (dermis) and fatty tissue (hypodermis). Of embryologic origin, the epidermis develops from the ectodermis while the dermis and hypodermis have mesodermal origin. [3]

From the functional point of view, epithelia divide in: covering epithelia, glandular (exocrine – sebaceous, sudoriparous, salivary, gastric glands; and endocrine – they eliminate hormones, directly in the blood or lymph) and sensorial (enter in the structure or the peripheral segments of the analysers). The covering epithelia cover the body in the exterior (epidermis) or pad the cavity organs (mucosas). [4]

The epidermis is the superficial layer of the skin and it has a variable thickness in the various regions of the skin. It is made of the following layers: generator, polyedral cells, granular, cornous, exfoliated. During his life a man looses 18 kg of skin, through the continuous desquamation of the cells. The dermis is the layer under the epidermis, thicker than it and formed of conjunctive tissue, with abundant fundamental substances: fibroblasts, melanoblasts (pigmented cells), elastic fibres and reticulin, blood capillaries and nervous receptors. Melanogenesis is a biophysical process of the skin which produced the melanin pigment (melanin). The pigments in the black skin are more numerous, bigger, wider spread, with a high content of melanin; they are degraded slower through the liposome enzymes. The pigments in the white skin are smaller and aggregated in groups of 2–3; and a more rapid degradation is achieved.

The dermis also contains sebaceous glands, excretion channels of the sudoriparous glands (in the stress), the surface

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part of the pilifer follicles, the dermis' vascular network and the nervous receptors. [5, 6]

The hypodermis is the deepest layer of the skin, formed of lax conjunctive tissue, rich in adipose cells. They form the so called adipose panicle, with a variable thickness in the various regions of the skin, presenting sex and individual particularities. The adipose panicle has a role in thermoadjustment, reducing the body's heat loss and it also represents a fat deposit. In the hypodermis there is the secretor part of the sebaceous glands, the deep part of the pilous follicles, the subcutaneous vascular network, the cutaneous nerves and the nervous receptors. The sudoriparous glands are of two types: eccrine (spread randomly on the entire surface of the teguments, in a total number of 2–5 million, they have the highest density in the palms, soles, being more numerous in men) and apocrine (they are disposed in the axillary, perineal-genital regions and at the level of the mammary areolas; the secretion process start with puberty, under the action of the sexual hormones; the secretion is performed continuously, but the excretion is episodic). [7]

Sweat is a clear, hypotonic, smelling solution with a specific density between 1,001–1,015 g/cm^3, pH between 4,5 and 5,5, amount of 0,5 litres/day. It contains 99% water and 1% dissolved substances. The mineral compounds are represented by Na, Cl, K, Ca, P, Mg, I, bicarbonate, sulphate, Fe, Zn and other. From the nitrate compounds, the eccrine sweat contains proteins and substances resulted from their degradation: urea, uric acid, creatinine, ammonia, amino acids and the non nitrate ones – lactic acid, traces of glucose, vitamins (C, B_2, B_6) and other. In its composition can also be traced immunoglobulines, histamine, bradykinin, prostaglandines, proteolytic enzymes, proteases) and other.

The factors which intervene in the control of the sweat secretion are intrinsic and extrinsic. From the intrinsic factors, the nervous ones have an important role. The sudoriparous glands on the palms, soles, forehead and axillas respond predominantly to emotional stimuli. Other intrinsic factors involved in the adjustment of sweat are hormonal factors. Aldosterone and the antidiuretic hormone determine the reabsorption of Na in the epithelium of the sweat canal. The thyroid hormones favour the reabsorption of the electrolytes.

The extrinsic factors involved in the control of the eccrine sweat secretion are the caloric stress, the physical exercise and so on. A person under high temperatures can eliminate 2–3 litres of sweat/hour. The physical exercise determines an even higher increase of the maximum sweat in the hot environment. In the conditions of a prolonged caloric stress [8], such as in the tropical climate, the eccrine sudoriparous glands become „acclimatized", gaining the ability to respond more intensely to relatively small increases of the body temperature.

Fanners are skin annexes with protection role, visible on the surface of the skin and represented in humans by hair and nails. The hair has the function of protection in humans, being only a body ornament, with an important psychological role. The hair growth rhythm varies with species and region of the body, a daily growth ration is 0,37 mm for the hair of the human scalp (in man the beard 0,4–0,6 mm) and the thickness ranges from 0,07 – 0,17 mm.

TABLE 1. Quantity of human hair

Colour of hair	Number of hair
Blond	140.000
Broun	109.000
Black	102.000
Red	80.000

In women, the scalp hair grows faster and the body hair slower then in men. We have 150.000 hairs which grow in total 16–40 m/24 hours; we loose 40–120 hairs a day. The growth ratio of the body hair in human is increased by the androgen hormones and it is diminished by the estrogenic hormones, on the upper lid the number of eyelashes is 140–200 and the length is 8–12 mm and on the lower lied there are 50-100 with a length of 6–8 mm. [9]

The sebaceous glands, regularly attached at the hair root are acinus type gland, situated in the dermis, with the dimension of 0,2–2mm. The fatty secretion product, called sebum is eliminated at the hair root and on the surface of the skin through a very short excretory canal.

The mammary glands are situated on the anterior side of the thorax, between the 3rd and 5th intercostal spaces. Their growth in volume at puberty represents one of the secondary sexual characteristics. At the tip of the mammary papilla there are 12–20 orifices of the lactiferous canals.

The nail is a protection organ, of corneous structure, situated on the dorsal side at the tip of the fingers. It is made of a visible part called the nail body and a hidden part, covered by a fold of skin called nail root. The human nail is a few tenths of millimeters thick, translucent, shiny surfaced, hard, but flexible cylindrical horny layer. On the one hand, it is the protective shield of the distal phalanx exposed to many mechanical impacts, on the other hand, it is a quite important mechanical "instrument". First, it is a sharp tool, scraper, chisel on the human hand, while – when using them in pairs – it can be function as a tweezer for gentle grasping or rough defense – scratching. Toenails have little significance in this respect.

The growth of the nail is due to the gradual hornification of epithelial cells, approximately in the middle of the back of the distal phalanx. The nail growth ratio is 0,5–1,2 mm per week for the hand nails. The toe nails grow twice that slow, being thicker. The growth ratio is higher during summer, in hot climate, in the second part of life, during pregnancy, after traumas, after avulsion; starvation and some viral infective diseases lead to the reduction of nail growth or the thinning and wrinkling of the nail.

The hand nail growth speed was modelled by Vincze [10]:

$$D = \sqrt{c \cdot t}$$

where: D – is the length in mm; t – time (in weeks); c ≈ 0,5–0,9. The shape and size of the nail are important hereditary characteristics.

III. Pain Reception

Unlike all others pain receptors do not have an adequate stimulus. Painful, or nociceptive, sensations can be caused by any stimulus of excessive intensity. Because such stimuli damage tissues, the painful sensations arising from them are of

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great biological importance signalling danger to the organism and arousing defensive reflexes intended to eliminate the painful stimulus. As the French philosopher Voltaire wrote more than 200 years ago, “pain is a vigilant guard against all our dangers; pain loudly tells us over and over again: take care, save your life”.

Painful sensations are often the first, and sometimes the only, manifestation of disease that help to establish its diagnosis, determine its gravity, and prescribe proper treatment. The gravity of a disease, however, does not always correspond to the intensity of the pain. Serious ailments of the internal organs often have no attendant painful sensations; conversely, not infrequently a most excruciating pain is caused by a negligible, innocuous malady, and is the principal cause of suffering. [11]

It is still an open question which of the nervous structures are sensitive to pain. Some investigators maintain that there are no special receptors for feeling pain, since overstimulation of any receptor or nerve trunk can cause pain. Others believe that painful stimuli are sensed by the free endings of nociceptive fibres.

The main evidence of the latter view are the following facts.

(1) There is a condition known as analgesia in which pain is absent though the sense of touch is retained (it appears in light general anaesthesia, and in certain diseases of the spinal cord); in it incision, of the skin is felt as a touch and a pressure rather than as pain.
(2) There are specific puncta dolorosa (painful points) in the skin; in pricking various areas of the skin with a very fine needle, one may hit upon points where pain is aroused immediately without a preliminary sensation of touch. In the middle of the cornea there are no tactile points but there are painful points; histological studies indicate that only the naked branches of sensory nerves are ramified there without specific tactile corpuscles.
(3) After a nerve has been severed and sutured, sensation of pain is recovered first during regeneration, and only some time later the other forms of sensibility. Upon recovery of sensibility to pain alone any irritation of the skin – touching, stroking, pressure – often causes a feeling of unbearable pain. With recovery of other sensations (tactile, heat, cold), the painful sensations cease to be excessive and return to normal. In essence this succession in the recovery of sensation after a nerve injury corresponds to definite morphological stages in the regeneration of damaged nerve trunks and receptors. In the early stages of regeneration nerve fibres have no medullary sheath and are free nerve endings (naked axis-cylinders). It is then that any irritation is perceived as pain. As the medullary sheath appears and the structure of the receptors is restored the skin recovers its normal sensibility, and the excessively painful sensations disappear. [12]

Biophysical research on the afferent impulses conducted by the nerve trunks and fibres under the action of painful stimuli have shown that impulses causing the sensation of pain are transmitted by two types of fibre. Some of them belong to group Aδ; these are thin medullated fibres conducting excitation at a speed of 5 to 15 metres per second. Others are thin non-medullated fibres belonging to group C, which transmit impulses at a speed of one or two metres per second. In accordance with the different speeds of transmission and, consequently, the different times of arrival of the painful impulses at the central nervous system, painful stimuli cause what seems to be a double feeling, at first transient and precisely localized, but not very painful, which is replaced by a diffuse, dull, subjectively very disagreeable and intense painful sensation.

There is a suggestion that a feeling of pain occurs when synchronous discharges of nerve impulses arise simultaneously in a very large number of afferent fibres. This helps explain why any irritation of the skin receptors is perceived as pain, during the regeneration of fibres, when the medullary sheath has not yet formed. The absence of the sheath facilitates the simultaneous involvement of many fibres in the process of excitation.

IV. THE BIOPHYSICAL MODELING OF THE ACTION POTENTIAL

Receptors can be regarded as analogue signal-convertes that transform sensed stimuli into electric signals, in other words, into membrane potential changes. This is the so-called receptor potential. [13] The nerve fibres connected to the receptor transform stimuli above threshold into a sequence of action potential (Figure 1.) whose frequency is the function of the receptor potential. This frequency-coded series of impulses propagates via the nerve fibre and reaches the corresponding sensory centre of the cortex. [14]

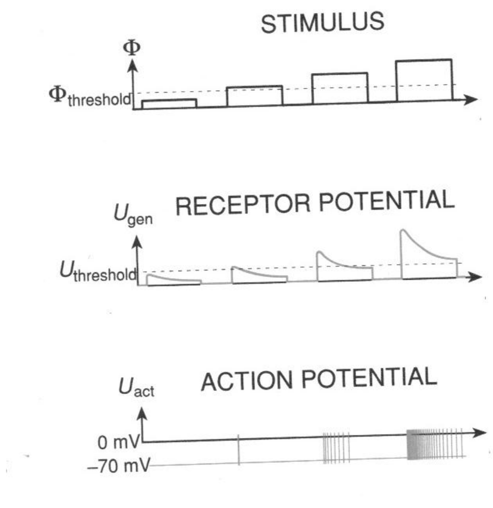

Fig. 1. The effect of stimuli with different strengths on the receptor potential and the formation of action potentials.

The mechanism of nerve transmission is as follows. As a result of the action potential at the presynaptic nerve end, the vesicles fuse with specific sites on the presynaptic membrane, thereby bringing the mediator into the synaptic cleft. [15] From here, its molecules reach the postsynaptic membrane by diffusion and alter its conductivity to the sodium ion. The

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current of the postsynaptic membrane changes as a result of the current of sodium ions: this is the postsynaptic potential. Experience has shown that the postsynaptic potential is composed of small doses; this corresponds to the synaptic potential created by a vesicle. In terms of their function, synapses are of two types: stimulatory *and* inhibitory synapses. In the case of stimulatory synapses, the postsynaptic potential means depolarization, and in the case of inhibitors, hyperpolarization.

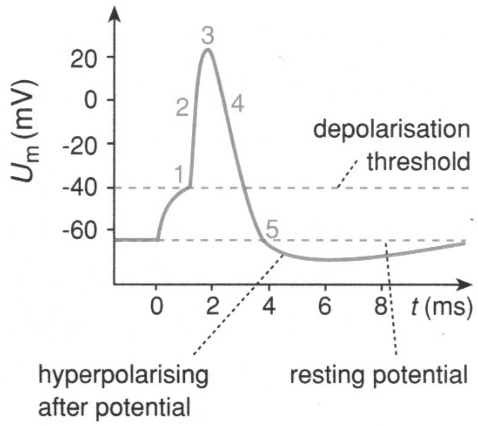

Fig. 2. The action potential

The biophysical modeling of this graphic is next function (after Vincze) [16]:

$$f(U) = \begin{cases} \dfrac{2t(4-t)*(t-10)}{\dfrac{t}{6}+1} & 0 \le t \le 4 \text{ [msec]} \\ \dfrac{4-t}{t^2-3t} & 4 \le t \le 10 \text{ [msec]} \end{cases}$$

V. The Function of the Human Tegument

The skin, the external layer of the human body has a lot of other functions. It is a protection organ from the physical, chemical, microbial agents; it is an excretion organ, through the sweat secretion, eliminating water, urea and other metabolism products; an absorption organ of some medicines; an organ with important thermoadjustment functions, participating in the maintenance of the body's thermal homeostasis haemodynamic functions, storing in the capillary networks or sending, upon need, an important amount of blood in the circulation and also an organ with meaningful metabolic functions. As a consequence, skin has its own pathology, with numerous implications in the entire body.

Mechanical, chemical, thermal, antimicrobian properties and water tightness are due mainly to the corneous epithelium of the epidermis rich in keratin. Another element which contributes to the achievement of the function of skin defence is the structure of the dermis (cells, fibres and intercellular matrix), which makes it mechanically resistant. The hypodermis, constituted of adipose tissue has a thermal and mechanical insulation role. It also represents an energetic reserve placed in an optimal solution for the organism.

The activity of the sudoriparous glands has a special importance in the removal from the body of some metabolic waste substances, considering that this way it could replace the excretory activity of one kidney. The role of the caloric stress in the stimulation of the eccrine sudoriparous secretion is well known. Through the evaporation of the water excreted at the surface of the skin, the excessive heating of the body is prevented 1 litre of sweat removes 2840 de kJ.

Skin has an important role in the haemodynamic adjustment mechanisms, through its richness of vascular plexi and the possibility to make significant amounts of blood stagnate at this level. They can reach up to 30% of the circulating blood mass in the conditions of the generalized peripheral vasodilatation.

The skin fulfils an important role not only in the protection of the organism from various factors from the external environment: mechanical, physical, chemical, biotic as well as the achievement of the complex defence function.

Skin is an important receptive field, due to the numerous and various terminations of the cutaneous analyser which informs the nervous centres on the proprieties and phenomena that the body gets in contact with. In the skin there are tactile, thermal, painful, pressure and vibration receptors.

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