Nerve conduction in the skin

The skin is the largest sense organ of the human body. It is responsible for perceiving cold, heat, touch, pressure, and pain. For each type of perception, there are specific sensory cells that receive the external stimuli and forward them to the nerve cells.

Cells of the nervous system

The human nervous system consists of two types of cells, nerve cells and glial cells. The **glial cells** (connective tissue cells) help the nerve cells during substance transport and provide structural support. There are substantially more glial cells than nerve cells. Glial cells have the ability to divide. **Nerve cells** (neurons) transmit information, such as sensory stimuli, to the brain as electrical signals. Nerve cells are highly specialized, and their function depends on their interconnection with other neurons. Unlike glial cells, nerve cells cannot divide. Thus, if a nerve cell is destroyed, it cannot be repaired again.

Structure and function of nerve cells

The functions of nerve cells can vary widely, but their basic structure is always identical:

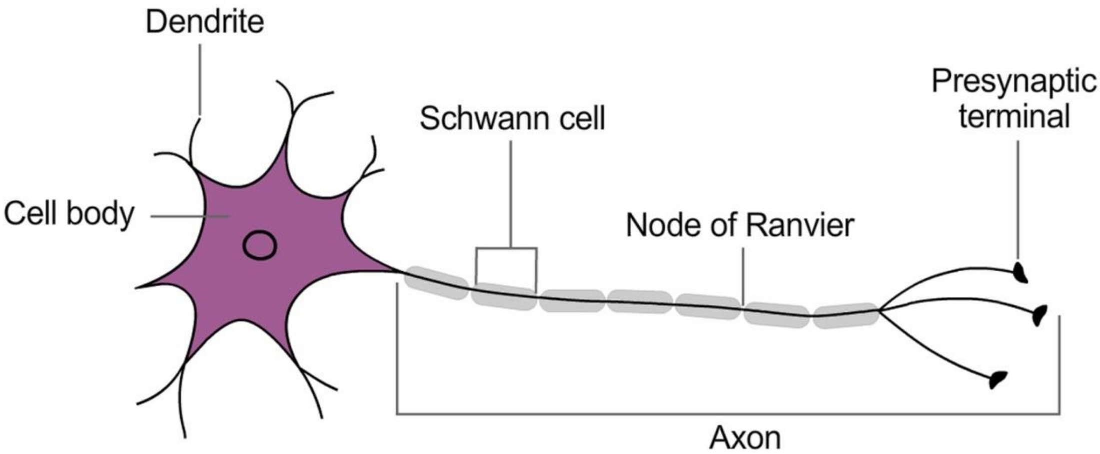

Fig. 1: Basic structure of a nerve cell

The center of the nerve cell is the **cell body**. It is responsible for the cell's growth and contains the cell components that are necessary for the production of proteins (protein biosynthesis). A large number of branches emanate from the cell body, the **dendrites** (Greek dendron = tree). Their task is to receive signals from other neurons and to forward the signals to the **axon** (nerve fiber). The axon is a single, very long cell projection that forwards the signals as electrical impulses. In vertebrates, the axon is frequently surrounded by a **myelin sheath**, which consists of special glial cells (the Schwann cells). The myelin sheath functions as an insulator for the electrical signals. It is interrupted at regular intervals. These gaps are called **Nodes of Ranvier**. The electrical impulses "jump" from node to node.

The axon branches out at the far end. The branches thicken at the end, forming **presynaptic terminals**. They adjoin with the dendrites of other nerve cells, although a small gap (synaptic gap) always remains between the cells. These junctions are called **synapses**. They transmit the signals from one nerve cell to the next.

Stimulus conduction

If a stimulus is exerted on the skin (e.g., through touch or heat), the affected receptor immediately transmits an electrical impulse to the next nerve cell. In this way, the impulse travels across several nerve cells and finally reaches the spinal cord and then the brain, which ultimately processes the information.

Generation of an electrical impulse:
Each cell has a certain membrane potential (more precisely, a potential difference), which arises due to the unequal distribution of positively and negatively charged ions inside and outside the cell. In relaxed nerve cells, the inside of the axon is normally negatively charged, and the outside is positively charged (e.g., due to the presence of Na+ ions). A certain baseline voltage can be measured, called the **resting potential** (approx. –70 mV). If a stimulus is exerted, the voltage increases and the **action potential** (-40 to +30 mV) is triggered. Special channels open in the axon so that part of the positive charge flows from the outside to the inside. This results in depolarization, that is, the charge ratios reverse. Since the axon is surrounded by the insulating myelin layer, depolarization occurs only in the area of the nodes of Ranvier. The action potential is transferred from node to node. The transfer of the electrical impulses in "jumps" is called **saltatory conduction**. The positive charges (electrostatic forces) are then transferred to the next section of the axon until they reach the presynaptic terminal. The terminal contains various neurotransmitters, which become activated by the action potential and dock with the ion channels on the outside of a dendrite across the synaptic gap. These ion channels then open and allow positively charged ions to pass through. The action potential is thus "transferred" to the next neuron.

Sensors in the skin

Skin can be roughly divided into three layers: epidermis, dermis, subcutis. The sensory nerve cells (nerve endings and receptors) that react to pain, pressure, and temperature are each located in specific layers of the skin.

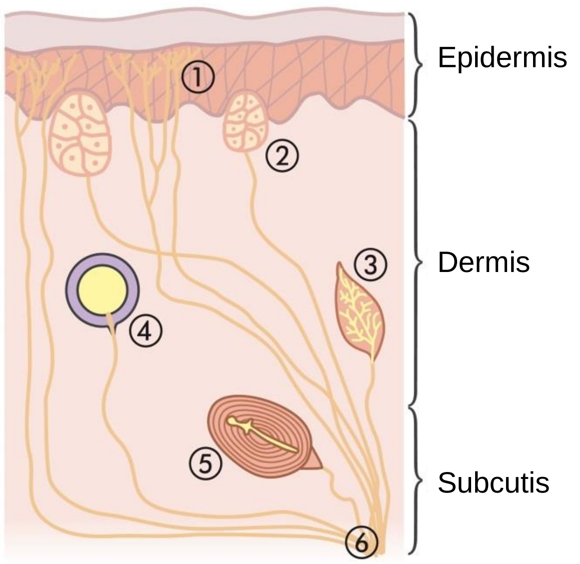

Fig. 2: Cross section of the skin

① Free nerve endings:
These receptors can sense pain, itch, and tickling. Because pain sensitivity is especially important for survival, free nerve endings extend into the epidermis to enable people to experience ideally all pain stimuli. One cm^2 of skin contains up to 170 free nerve endings. This explains why – other than areas covered by thick calluses – there are no areas of skin where the surface is impervious to pain. The areas that are insensitive on the surface have deeper pain receptors that react to substances released when tissue is damaged.

② Meissner's corpuscles (tactile corpuscles):
These receptors react to changes in pressures and thus to light touch and shear forces, and are especially numerous in the fingertips and the oral mucosa, i.e., places where we do the most testing of objects and substances in the environment. They are less numerous on our backs. Meissner's corpuscles provide information on the surfaces of objects. There are other types of tactile corpuscles.

③ Cold receptors:
These receptors are located in the upper region of the dermis and are responsible for the perception of cold. Unlike a thermometer, they are incapable of measuring absolute temperatures and can perceive only temperature differences. They react to a drop in temperature and trigger a sensation of cold, and are most sensitive at ambient temperatures of around 25 °C. On the back of the hand, there are up to eight receptors per cm^2 of skin; in contrast, there are up to 20 receptors per cm^2 on the tongue.

④ Heat receptors:
These receptors are also located in the dermis. They react to a rise in temperature and are thus involved in sensing heat. On the back of the hand, there is one receptor per cm^2 of skin. Overall, there are few fewer heat receptors than cold receptors.

Frequency encoding of nerve signals:
Both types of thermoreceptors ③ and ④ are constantly sending impulses to the brain. The frequency of the impulses depends on the temperature. Heat and cold receptors change the impulse frequency in response to cold and heat stimuli: Cold receptors send more action potentials per unit of time as the temperature decreases. Heat receptors do the opposite, i.e., they send more action potentials as the temperature increases. After a certain amount of time, the frequencies of the action potentials sent by cold and heat receptors adjust to the prevailing temperature. No additional temperature change is perceived until there is another change in temperature.

⑤ Vibration receptors (Pacinian corpuscles):
These receptors are involved in sensing fast vibrations and react to changes in the shape of the skin. They're mostly located in the transitional area between the dermis and the subcutis.