Cell Biology: Cellular Organization, Division and Processes

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Lecture 32

Nerve cells

Hi, I am Shikha Laloraya, Professor of Biochemistry, at IISc. Welcome to this lecture on nerve cells that are specialized cells of the nervous system and that generate and conduct electrical impulses in the body.

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Nerve cells or neurons are cells of the nervous system and they are specialized for communication. The nervous system includes the central nervous system and the peripheral nervous system. The central nervous system as you know consists of the brain and the spinal cord and this receives, processes, and stores information. The peripheral nervous system consists of sensory, that is carries information to the brain and the spinal cord, and motor divisions. Motor means they carry information from the central nervous system to other parts of the body.

So, nerve cells or neurons are highly specialized cells that transmit signals throughout the body. They are non-dividing cells that permanently stay in G_0 phase throughout adult life; these cells are specialized for communication. They generate and conduct electrical impulses termed action potentials. These cells are very long and highly polarized.

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This illustration here shows an artist's impression of nerve cells or neurons. So, there are actually three categories of neurons in the nervous system, one is a sensory neurons, these neurons respond to stimulus and transmit this information to the central nervous system in the form of electrical impulses. Motor neurons transmit impulses from the central nervous system to other tissues and organs of the body. And interneurons are connecting neurons they transmit information between parts of the central nervous system. For example, they receive input from sensory neurons, integrate this information and then they transmit it to other neurons. Nerve cells are highly differentiated and they have processes such as axons, this long process over here is referred to as an axon, and

dendrites that connect with other cells are for communication. The dendrites are relatively shorter projections, whereas the axons can be very long.

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Shown here is the structure of a neuron. Neurons consist of a cell body, an axon and one or more dendrites. The dendrites, they receive information from receptors or impulses from other neurons. Motor neurons and interneurons have got many dendrites projecting from the cell body. The dendrites of the sensory neurons interestingly connect directly to an axon. An axon is a long tube originating from the cell body, as you can see, at a projection referred to as the axon hillock. At the other end the axon branches into extensions termed axon terminals and each of the axon terminal ends in a small, rounded axon bulb.

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The cytoskeleton is particularly important in neurons for shaping it and it has got a specialized organization. So, I already mentioned neurons are polarized cells and they have these two types of processes extending from the cell body, the dendrites, which are the short processes that receive signals from other cells and the axons, a single long process that carries impulses to other cells such as other neurons or effector cells such as muscle cells. So, these axons and dendrites are supported by microtubules and neurofilaments. They have a plasma membrane and a small amount of cytoplasm as well and a lot of transport also goes on inside these processes. Microtubules in nerve cells are different in that they are not anchored to the centrosome. Stable microtubules in both the axons as well as the dendrites terminate in the cytoplasm and their ends are stabilized by capping proteins.

In the axon the microtubules are oriented with their plus ends pointing towards the tip of the axon, that is away from the cell body, which is a normal orientation for a microtubule. In dendrites though microtubules are oriented in both directions with their plus and minus ends pointing both towards and away from the cell body. Microtubule associated proteins or MAPs, which are important normally for the stability and properties of microtubules, they cap the plus and minus ends. And they also stabilize the microtubules by binding along their length for example the tau protein in axons and the MAP2 in dendrites. So, axons and dendrites have distinct distributions of MAPs; axons have tau proteins but no MAP2, whereas dendrites have MAP2 but no tau proteins.

In addition, neurofilaments are intermediate filaments, which are 10 to 12 nanometers in diameter intermediate between microtubules and actin. In neurons, intermediate filaments are formed of these neurofilament proteins NF-L, NF-M and NF-H, which stands for light medium and heavy forms, and alpha-internexin.

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Shown here is a structure of a myelinated motor neuron of the peripheral nervous system. Now in the nervous system only 20% of the cells are neurons, the remaining cells are supporting cells that provide protection and support to the function of the neurons, and these are termed neuroglial cells and these cells do not generate or transmit impulses. So, in the peripheral nervous system, the axons of many of the neurons are enclosed and protected by specialized neuroglial cells termed as Schwann cells, which is shown over here. The Schwann cells, they produce a fatty insulating material which is termed myelin. So, this myelin forms a protective layer around the axon and this layer is referred to as a myelin sheet, and this wraps different segments of the axon, you can see here. And between the adjacent Schwann cells are uninsulated sections term nodes, this section or region is referred to as nodes of Ranvier.

So, myelination increases the speed and efficiency of propagation of action potential in nerve cells and it also protects them. In the central nervous system, the sheath is also there but it is produced by cells termed oligodendrocytes, instead of Schwann cells.

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Neurons initiate action potentials. An action potential is a sudden temporary reversal of voltage difference across the cell membrane. The action potential, which is an electrical impulse, sweeps down the axon until it reaches the axon terminals. The details of this process are more appropriate for a more specialized discussion, but when the action potential reaches the axon terminals, the information must be converted to another form, for transmission to the appropriate target cell, which could be a muscle cell or another neuron or glands in the body. So, this elicits the release of chemical signals termed neurotransmitters at the junction between the two cells, which is referred to as a synapse. This process of transmission of information from a neuron to its target is termed synaptic transmission. For example, nerves can activate muscle cells by synaptic transmission across a nerve and a muscle cell and also they can communicate with other nerve cells as well.

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Seen here is a synapse between two neurons. At the synapse, the neuron, which is sending the information in the blue here is referred to as a presynaptic neuron and the cell which is receiving the information is the postsynaptic neuron. And in addition, this fluid-filled gap between the pre and the post-synaptic membranes of the synapse is referred to as the synaptic cleft.

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Now the axon bulb of the terminus of the presynaptic neuron has got neurotransmitters, which are stored in vesicles. Arrival of the action potential at the axon bulb causes calcium channels to open up in the membrane and calcium enters into the axon bulb. The entry of calcium causes these vesicles to fuse with the presynaptic membrane and therefore the neurotransmitters are released into the synaptic cleft.

The neurotransmitters bind to receptors on the surface of the postsynaptic membrane and this results in ion channels for example for sodium ions, to open up and sodium ions can enter and they produce a graded depolarization of the postsynaptic membrane. The neurotransmitters can have excitatory or inhibitory effects on the postsynaptic cell.

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Some common neurotransmitters are listed here; one of them is acetylcholine. Acetylcholine is released at neuromuscular junctions in the autonomic nervous system and in the brain and it has excitatory action on muscles. And it is excitatory or inhibitory elsewhere depending on the receptors that are present. Acetylcholine travels from the neuromuscular junction and it binds to acetylcholine receptors, which are activated and they can generate the muscle contraction.

Interestingly in an autoimmune disease Myasthenia gravis, autoantibodies block, alter or destroy the receptors for acetylcholine at the neuromuscular junction, which prevents the muscle contraction from occurring. These antibodies in this disease are produced by the body's own immune system as it is an autoimmune disease.

Serotonin is another neurotransmitter which is released in areas of the brain and spinal cord, and it has usually inhibitory effects involved in mood, sleep cycle and appetite. Dopamine is released in areas of the brain and parts of the peripheral nervous system, and it could also be either excitatory or inhibitory depending on the receptors present and it has a role in emotions. Glutamate is an important neurotransmitter which is released in the areas of the brain and spinal cord, and it is usually excitatory and it is the main neurotransmitter present in the brain. And also, there are several other neurotransmitters not listed here.

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An interesting property of the neural processes of neurons is self-avoidance. What this means is that the dendrites and axons of the same neuron avoid making contact or connections with each other. Axons and dendrites from the same neuron will not make the connections with each other but prefer to make the connections with axons and dendrites from other neighbouring neurons. So, this helps introducing the formation of purposeless synapses with itself and also it helps in these processes to spread out more widely and innervate a larger territory.

So, how can these processes distinguish between self and non-self? This is an interesting question. For this, there is a class of proteins term DSCAM in *Drosophila* and protocadherins in vertebrates, which are very important. In *Drosophila* there are nearly 30000 variants of DSCAM proteins that can be produced by alternative splicing and when two cell surfaces express the identical isoform this results in repulsion. So, neighbouring processes from different neurons are unlikely to express the same DSCAM variant. So, only the processes of the same cell repel each other whereas the process of other cells can establish connections with each other.

The protocadherin locus in vertebrates codes for 58 cadherin-like transmembrane proteins which are expressed in different combinations in individual neurons. The neighbouring dendrites of different neurons, they express different protocadherins and therefore they can avoid repulsion and they can establish connections with each other.

I hope with this lecture you have learned something about the structure, the complexity and the function of the nerve cells or neurons. Thank you.