Introduction to the Nervous System.

Code: HMP 100/ UPC 103/ VNP 100. **Course: Medical Physiology**

Level 1 MBChB/BDS/BPharm

Lecture 3. Cells of the Nervous System and Neural Circuits

Lecture Outline

1.1 Introduction

In this lecture, we will look at the cells that make up the nervous tissue and look at an example of a neural circuit. As we will see there are two classes of cells - neurons and glia, both of which come in sub-classes. After we have discussed these cells, we will look at a neural circuit to see how a response to a stimulus takes place. The neural circuit we will look at is the knee jerk reflex.

1.2 Learning Outcomes
At the end of this lecture, you should be able to:
1. Describe and explain the function of the nerve cells
2. Describe and explain the function of the glia cells
3. Draw the neural circuit diagram of the knee jerk reflex
4. Explain how the nerve signal is transmitted in the knee jerk reflex

1.3 **Nerve Cells**
Nerve cells or neurons make up around 10-20% of the cell population of the nervous tissue; the other 80-90% of the nervous tissue is made of glial cells. In terms of numbers, we have around 100 billion nerve cells. In tissues in other parts of the body we do not find much variation between the cells that make up that tissue. So it does not matter which part of the liver we look at, the cell types will be similar to other parts, and also how the cells are arranged, the cytoarchitecture, will also be similar in different parts of the liver. In the brain, we find that there is not this regularity of cells and cellular arrangement. We find that nerve cells come in many different forms and nerve cells arrangements in different areas of the nervous tissue can be very different.

In Figure 3.1 two types of nerve cells are shown: the cortical neuron found in the cerebral cortex and the motor neuron (alpha motor neuron) found in the ventral horn of the spinal cord gray matter. Both show a feature that is common to nerve cells. This is the processes that are produced and extend out from the **cell body**. The longest process is the **axon** and its ending makes the pre-synaptic part of the **synapse**. In Fig 3.1 (lower right), there also a picture of the ending a motor neuron showing the pre-synaptic part in contact with a muscle cell. In other lectures, we will discuss how the signal from the nerve cells is passed to the muscle cell to cause the muscle cells to contract.

Also extending from the cell body are processes that are shorter than the axon and have lots of branching. Because the branching of these processes look like a tree, they are called the **dendrities** from the Greek word, *dendron*, meaning tree.

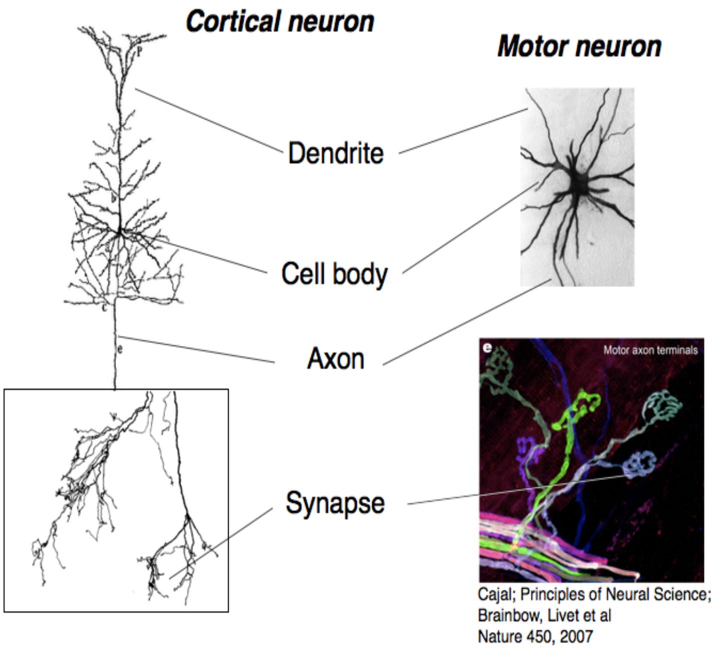

Figure 3.1. A cortical and motor nerve cell. Note that both have a long process called the axon and many shorter processes called the dendrites.

We can divide a nerve cell into 4 anatomical compartments: (1) dendrites, (2) cell body, (3) axon and (4) synapse.

Like all other cells of the body, the cell body of the nerve cells contains all the cellular organelles necessary for cell function. But we may wonder how material from the cell body is sent along the long axonal processes as these processes can be quite long. For example, the pyramidal cell in our motor cortex sends axons that extend all the way to the lumber region of our spinal cord. This is a distance of around a meter, and if we consider the giraffe, the same axons can extend over 2 meters. Because the speed of diffusion of molecules would be too slow to sent material rapidly along the axon, there is a mechanism made up of specialized molecular machinery to move material from the cell body along the axon (anterograde) and from the nerve ending to the cell body (retrograde). This is a molecular transport machinery that moves material at a rate of 400 mm/day (fast transport) and another that is slower moving the material at a rate of 200 mm/day (slow transport).

	On the internet look the diffusion rate of molecules in a liquid. Calulate the time if would take a molecule to diffuse 1 meter.

Now if we look at how the nerve cells connect to each other, we find that the nerve endings from other nerve cells make connections on the dendrites and cell body, not on the axon. Looking closely at figure 3.1, we see that dendrites have tiny extensions on their branches. These are called the **dendritic spines**, and it is on these that axons from other nerve cells make connections. So the dendrites and cell body make up the **input zone** of the nerve cells. Signals from the nerve cell are sent along the axon to other cells, so the axon is the **output zone**.

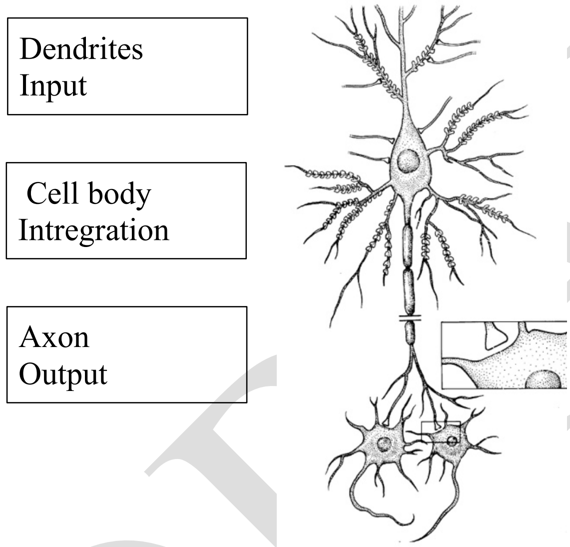

Figure 3.2. Diagram of a nerve cell showing the input zone (dendrites), the integration zone (cell body), and the output zone (axon).

Now if we ask how many connections does a singe nerve cell receive, the answer is astonishing. On the average a nerve cell in our brain and spinal cord receives 1,000 synaptic connections, some up to 10,000. This means that the nerve cell is receiving 1,000 signals and these signals have to be integrated to “decide” what the nerve cell should do. Our nerve cells have to “decide” whether to send a signal to the cells it contacts to or not. How do our nerve cells make this “decision”? We will not discuss the “decision” making process in this lecture

	On the internet look up the meaning of the word integration.

but it will depend on how the incoming signals change the nerve cell membrane electrical potential. This takes in the cell body and hence the cell body is the **integration** zone.

When the axon makes a connection with another nerve cell, it passes the signal to the other cell by releasing chemicals from its nerve endings. These are called neurotransmitter, and we will discuss the process of signal transmission at the synapse, in the lectures on synaptic physiology. We should also note that when the axon reached the cell it will form a synapse with it forms several branches. We can see this for motor and sensory nerves in figure 3.2.

The human brain has around 100 billion nerve cells. If on the average each nerve receives 1,000 synaptic connections, how many synaptic connections are there in the brain?

Finally, we should know the different types of nerve cells that we can find in the nervous system. In Figure 3.2 drawings of the different shapes (morphology) of nerve cells are shown. All the nerve cells have dendrites, a cell body, and an axon. But we see these parts of the nerve cells differ between nerve cells forming nerve cells with different morphologies. Also in figure 3.2, the names of the different types of neurotransmitters that are released by the nerve ending are given. So nerve cells also differ by the neurotransmitter that is released by their nerve endings at the synapse.

An important principle of neuronal functions is that a nerve cell releases only one type of neurotransmitter from all its nerve ending. So a nerve cell does not release one type of neurotransmitter from from one of its nerve ending and another from its other nerve ending. It is called **Dale's Principle**.

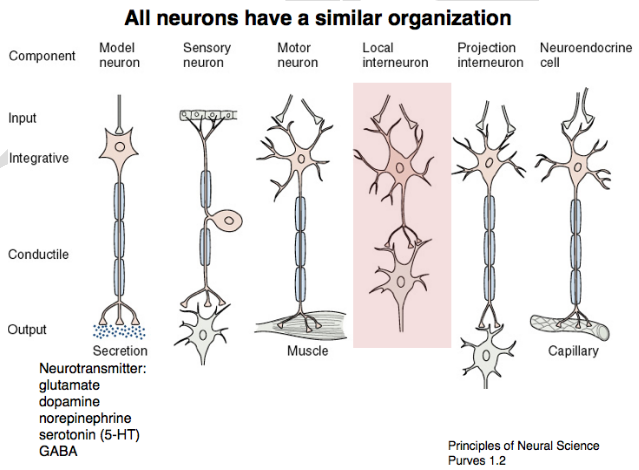

Figure 3.2. Diagram of the different types of nerve cell morphology and some of the neurotransmitter that released by nerve ending.

So in this section, we have looked at the parts of the nerve cell.

1.4 Glial Cells

In this section, we will discuss the glial cells, which were considered to glue the nerve cells together, hence the name glia. But now we know, that the glial cells carry out many different functions in the nervous system. Unfortunately, we tend not to take them too seriously, being more fascinated by the nerve cells.

Figure 3.3 nicely summaries the many functions that our glial cells carry out. They are divided into those found in the PNS and CNS. In the PNS, the **Schwann cells** wrap around the axons, a process called myelination, while in the CNS it is the **oligodendrocytes** that make the myelin sheath. The **myelin sheath** increases the speed at which nerve signals can travel along the axon. We will learn more about this process during the lectures on electrical signaling in nerve cells. In the CNS, there are also a class of glial cells called **astrocytes**, so called because they look like stars.

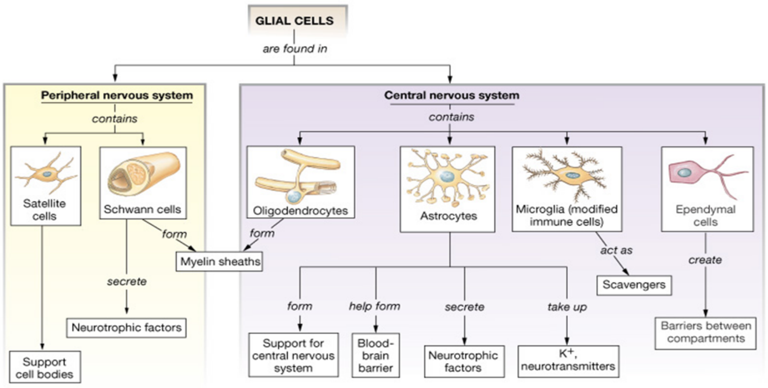

Figure 3.3. Diagram showing the different classes of glial cells and their functions.

In figure 3.4 stained in green are the astrocytes and stained in red are the oligodendrocytes. The blue circles are the nuclei of the cells. Astrocytes perform many functions in the brain. One function is to secrete **neurotrophic factors**. These are proteins that are necessary for the growth and survival of developing nerve cells and maintain the health of the mature nerve cells. The **microglial cells** functions as immune cells and are activated when there is infection or trauma to our brain. They remove dead cellular material in the brain.

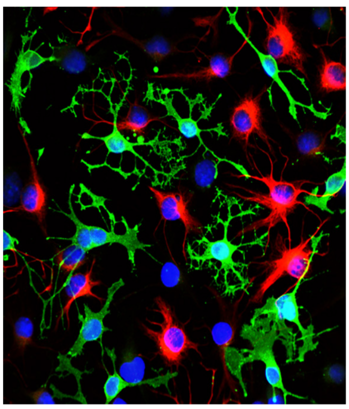

Figure 3.4. Glial cells with astrocytes stained green and oligodendrocytes in red. Blue circles are cell nuclei.

Unlike other parts of the body, the CNS has a barrier that controls which substance can enter and leave the CNS. This is called the **blood-brain barrier** and involves both the **ependymal cells** and the **astrocytes.**

Now that we have discussed the cells of the nervous system, we will look at a simple neuronal circuit and see how a response is produced to a stimulus.

1.5 A Simple Neuronal Circuit

The neural circuit that we will look at is the **knee jerk reflex.** This a one of the **tendon jerk reflexes**. Figure 3.5, shows that when the patellar tendon of the knee is struck with a reflex hammer, it causes an extension of the lower leg. This extension of the lower leg is without the person needing to "command" an extension; their lower leg extends involuntarily when the patellar tendon is struck. It is a reflex action. Reflexive activity takes place without us having to consciously produce a response to a stimulus. There are many reflexes in the body and each has a physiological function. Usually the circuit of the reflex is arranged so it acts as a negative feedback control system.

The stimulus, in this case the extension of the patellar tendon caused by the reflex hammer, causes nerve signals to be generated in the receptor. In this case the **muscle spindle** located in the quadriceps muscle of the thigh. The nerve signals travel along the **sensory** nerve fiber to the spinal cord and where the nerve fiber makes a synaptic contact on **motor neuron**. This an excitatory synapse and stimulates motor neuron to produce nerve signals. These signals travel along the nerve fiber of the motor nerve cell to quadriceps muscle causing it to contract. And this results in the extension of the lower leg. So this is simple neuronal circuit consisting a receptor, two nerve cells, and effector – the quadriceps. This circuit is shown in red in figure 3.5.

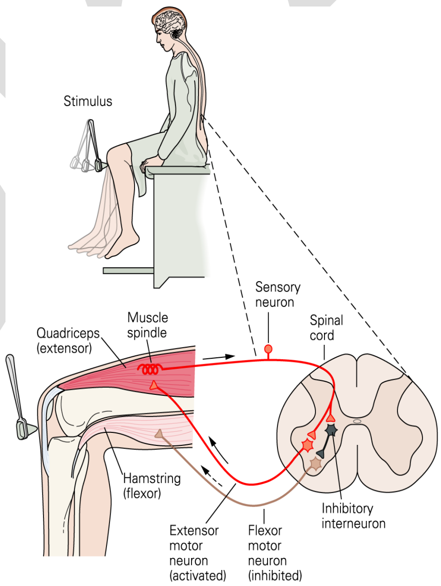

Figure 3.5. Circuit diagram of the knee jerk reflex.

In the circuit diagram shown in figure 3.5, we can see that the sensory nerve bringing the signal to the spinal cord has a branch that makes contact with another nerve cell shown in black colour, which turn makes a connection with another motor nerve cell shown in light brown colour. The nerve cell shown in black is called a **spinal interneuron**. Its axon does not leave the spinal cord but assist in making connections between nerve cells within the spinal cord. The signals it produces stops the motor nerve cell to which it is connected from producing any signals. Thus it is called an **inhibitory interneuron**; it inhibits the nerve cells it is connected to from producing any signals.

The motor nerve cell shown in light brown colour sends a nerve fiber that makes synaptic connections with the muscle fibers of the hamstring muscle. By preventing production of nerve signals in this motor neuron, the hamstring muscles are not stimulated to contract and so do not oppose the extension lower leg.

	Testing of tendon reflexes is routinely used by doctors during a clinical examination.

So in this section, we have looked at a simple neural circuit in which a particular response (extension of the lower leg) is produced when particular stimulus is applied. This is similar to the electrical wiring in a house. Different switches control different lights. So turning on the switch is the stimulus sending an electric current through the circuit and light coming on is the response.

1.6 Signaling in the Nervous System

In last section, we discussed the neuronal circuit for the knee jerk reflex. We saw that the circuit involves receptors, nerve cells and muscle cells. We looked at the path the signal took through the circuit to produce the response. In this section, we are going to discuss what these signals are?

Signaling in the nervous system involves chemicals and electricity. We will learn about chemical signaling during the lectures on synaptic physiology, and about electrical signaling in lectures about electrophysiology. Here we will briefly go over the different types of signaling used.

In the nervous system, chemical are used to pass signals from a nerve cell to other cells. We call the chemicals used for this purpose in the nervous system, neurotransmitters. The neurotransmitters are released by the nerve endings and interact with receptors on other cells. The region where this transfer of signal from a nerve cell to the other cell takes is called a **synapse**.

Electrical signaling is used by nerve cells and muscle cells. To understand how this electrical signaling can take place, we need to know that between the outside and inside of nerve or muscle cell there is an electrical voltage difference. This is called the **membrane potential**. It is quite small and measured in millivolts. By changing the value of the membrane potential, either increasing it or decreasing it, electrical signals are produced. And these changes in the membrane potential can moved along the cell membrane of the nerve cell and its fibers.

In figure 3.6, the whole neural circuit for the knee jerk reflex is laid out a straight line to make it easier to see the signaling process. Starting from the muscle spindle, we can see that when it is stretched (the stimulus), this causes the membrane potential in the nerve ending that makes contact with the muscle spindle to change. This is shown in the box under the heading sensory signals. It is labelled **graded receptor potential**. Than there is another change in the membrane potential produced, which called the **action potential**. While the graded receptor potential is found only in the nerve ending, the action potential travels along the nerve fiber till it reaches the end of the sensory nerve in the spinal cord. Here it causes the release of neurotransmitters. In the case of the knee jerk reflex, the neurotransmitter released is **glutamate**.

Glutamate causes the membrane potential in the cell body of the motor neuron to change. These changes in the membrane potential caused by neurotransmitters are called **graded synaptic potentials,** and can lead to production of action potentials, which travel along the axon until they reach the nerve ending. In this case the nerve ending is making contact with a muscle cell and it releases the neurotransmitter, **acetylcholine**, onto the surface of the muscle. This causes the membrane potential of the muscle cell to change (graded synaptic potential), which cause action potentials in the muscle cell and this in turn leads to muscle contraction. How does producing an action potential in the muscle cells causes the muscle to contract? We will learn about in the lectures on muscle physiology.

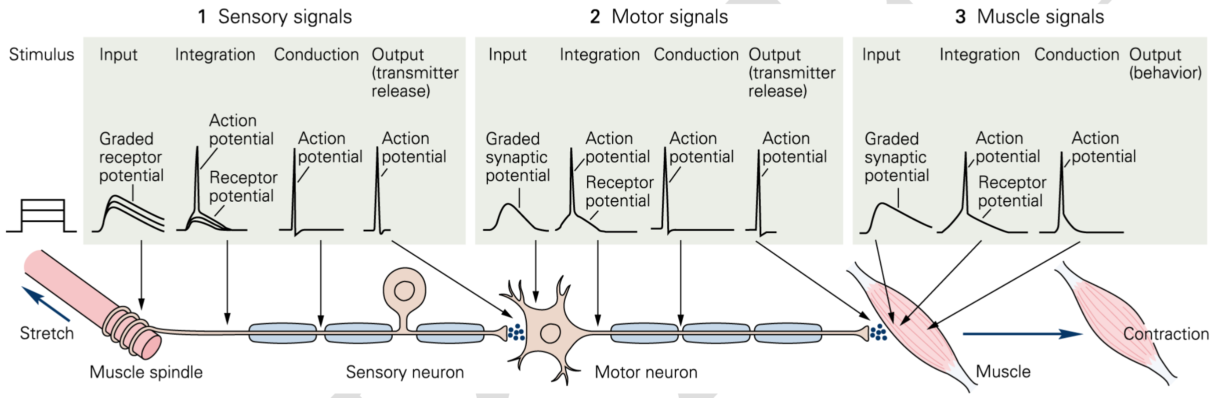

Figure 3.6. The electrical and chemical signals that are produced in the neural circuit of the knee jerk reflex to cause extension of the lower leg when the patellar tendon is struck.

So in this section, we have covered the nature of the signals found in the nervous system. These are chemicals, called neurotransmitters, and there many different types of neurotransmitters. The other type of signals produced are electrical and they also come in different types.

1.7 Summary

In this lecture, we have looked at the two different cell types that are found in the nervous system - the nerve cells and the glial cells. Then we looked at a simple neural circuit to see how a response is produced to a stimulus. This was the knee jerk reflex. Finally, we discussed the signals used by our nervous system, which are chemical and electrical. In the following lectures, we will cover in more detail the process of producing electrical and chemical signals, and then, different neural circuits that carry out the different functions of our nervous system.

1.8 Activities

1.9 Further Reading

1.10 Sample Examination Questions

Sample Exam Questions

Multiple Choice Questions (MCQs)
Select for each question, the best correct answer.

1) The sensory receptor for the knee jerk reflex is the
   a) Skin receptors
   b) Pain receptors
   c) Muscle spindle
   d) Touch receptors
   e) Golgi tendon organ
2) Sensory input to the spinal cord comes from the
   a) Dorsal side
   b) Ventral side
   c) Lateral side
   d) Sagittal side
   e) Coronal side
3) The input zone of the nerve cell is the
   a) Dendrites and cell body
   b) Cell body and the axons
   c) Axons
   d) Projection nerve fiber
   e) None of the above
4) The glia that provide the myelin sheath in the peripheral nervous system are the
   a) Schwann cells
   b) Oligodendrocytes
   c) Astrocytes
   d) Microglia
   e) Epyendemal cells
5) The glia that provide the myelin sheath in the peripheral nervous system are the
   a) Schwann cells
   b) Oligodendrocytes
   c) Astrocytes
   d) Microglia
   e) Ependymal cells
6) The neurotransmitter released by the sensory nerve of the knee jerk reflex is
   a) Glutamate
   b) Acetycholine
   c) Dopamine
   d) Serotonin
   e) Gamma amino butyric acid (GABA)
7) The change in the membrane potential produced by the release of the neurotransmitter is called the
   a) Generator potential
   b) Action potential
   c) Synaptic potential
   d) Receptor potential
   e) Membrane potential

Short Answer Questions (SAQs)

Note: SAQs have maximum of 5 marks. The answer to the question has to be precise giving all the key points required. If the SAQ requires a diagram or illustration, you must provide the drawing otherwise you will immediately lose half the marks. I would recommend that you practice drawing out key illustration or diagrams given in the lecture and in the textbooks.

1. Draw the neural circuit diagram of the knee jerk reflex.

2. Name the different glia cells of the nervous system and their function.

3. Draw a diagram of a nerve cell and label the 4 anatomical compartment and the role these compartments play in nerve cell function.