CHAPTER-8

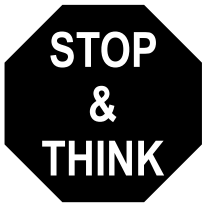
Nervous tissue

Core Resources
Tortora and Grabowski- Principles of Anatomy and Physiology
Chapter 12

Introduction

The function of the nervous tissue is in communication between parts of the body. It is composed of neurons, which transmit impulses, and the neuroglia, which assists propagation of the nerve impulse as well as providing support and nutrients to the neurons.

Learning outcomes



The student should be able to:

- Describe the structure and function of a neuron
- Identify the properties of a neuron
- Describe the concept of myelination

Nervous tissue

The function of the nervous tissue is in communication between parts of the body. Nervous tissue is found in the two main subdivisions of the nervous system. The central nervous system (CNS), which consists of the brain and spinal chord, and the peripheral nervous system (PNS), which includes all nervous tissue beyond the CNS. Nervous tissue is composed of two types of cell: **neurons**, which transmit impulses, and the **neuroglia**, which assists propagation of the nerve impulse as well as providing nutrients to the neuron.

The Neuron

The neurons actively generate and conduct the electrical impulses, known as **action potentials**. Throughout the body, the neurons are made up of essentially the same structure, although their shape may differ rather dramatically, depending on their location.

Basically the neuron consists of three parts:

1. **The cell body-** initiates or receives action potentials.

2. **The dendrites-** a nerve fibre (or process) receives the impulse, and carries it towards the cell body.
3. **The axon-** the process which carries the impulse away from the cell body, either towards the dendrites of another neuron, or to the effector organ.

1. **The cell body**

The cell body contains a nucleus, and is surrounded by cytoplasm, which contains the typical cellular organelles. The cell body also contains clusters of rough endoplasmic reticulum called **Nissl bodies**. These bodies synthesize protein, which replace cellular components and regenerate damaged axons of the peripheral nervous system.
Other groups of cell bodies, separate from these two main groups, are referred to as **ganglia** or **nuclei**.
The cytoskeleton contains neurofibrils and microtubules, to assist moving materials to and from the cell body to the axon.

2. **The Dendrites**

These are short, multiple and highly branched processes which extend from the neuron. Dendrites function in receiving impulses from other neurons, and transmitting them to the cell body of the neuron.

3. **The Axon**

The axon is always a single, usually long process (up to 1 metre), extending from the cell body, and transmitting the impulse away from the cell body towards the effector organ (muscle fibre or gland cell) or the dendrites of another neuron.

The cytoplasm of the axon is referred to as the axoplasm, and is surrounded by a plasma membrane called the axolemma (lemma – sheath).

Impulses travel along the axon by means of an electrical signal across the cell membrane. The axon terminates with branched axon terminals. When it reaches the end of the axon the signal needs to be transferred across to the next neuron or effector organ in the sequence. The site of communication between two neurons, or the neuron and effector organ is the **synapse**. The tips of the axon terminals expand to become **synaptic end bulbs**. These bulbs contain enclosed sacs called **synaptic vesicles**, which store the **neurotransmitter** (the chemical molecules which influence the behavior of the dendrites of receiving neurons, or muscle fibre and gland cells). These chemicals then pass over the gap (the **synaptic cleft**), and are recognised by receptors on the second neuron or effector organ, and then the information is processed by the receiving cell so that the impulse can continue or be acted upon.

Functions of Neurons

There are three basic functions: **sensory**, **integrative** and **motor**.

1. **Sensory** neurons detect internal and external stimuli and carry information to the brain.

2. **Integrative** neurons process sensory information for response or storage.
3. **Motor** neurons respond to integrative neuron decisions and effect (cause) a response.

<u>Classification of neurons</u>

Neurons are classified according to the number of axons and dendrites they have.

Bipolar neurons

- Have only one axon and one dendrite separated by the cell body.
- Found in the retina, inner ear, and olfactory region of the brain

Unipolar neurons

- Have a single process (fused axon and dendrite) with the cell body attached.
- Are sensory neurons.

Muitipolar neurons

- Have numerous dendrites and a single axon.
- Most common neuron in the CNS.

Neuroglia

These cells function to support the neurons, and are not involved in the initiation or conduction of nervous impulses.

<u>Neuroglia cells in the CNS</u>

Astrocytes:

- Maintain chemical the environment for the generation of action potentials
- Participate in the transport of nutrients from blood vessels to neurons
- Participate in the up take of, and metabolism of excess neurotransmitters
- Involved in the repair processes of the CNS.
- Assist with migration of neurons during embryonic development.
- Help form the **blood-brain barrier**. At the free end of some of their processes, are swellings called foot processes. Astrocytes are found in large numbers around the blood vessels and their foot processes form a sleeve around them, therefore the blood is separated from the neurons by a capillary layer and a layer of astrocyte foot processes. This is the blood-brain barrier. The blood-brain barrier is a selective barrier that protects the brain from chemical variations in the blood.

Oligodendrocytes:

- Produces and preserves the **myelin sheaths**

Microglia:

- Are phagocytic cells that remove dead and dying tissue and foreign material.

Ependymal cells:

- Epithelial cuboidal or columnar ciliated cells.
- Found in the ventricles and central canal of the spinal cord.
- Form the **cerebrospinal fluid** and assist in its circulation.

Neuroglial cells in the PNS

Schwann cells:

- Produce the **myelin sheath –** a phospholipid**.**
- Participate in the regeneration of the PNS axons.

Satellite cells:

- Support the neurons in the PNS ganglia.

Myelin

Groups of axons together form groups of nerve fibres. Axons can be myelinated or non-myelinated. Myelin is a sheath, which is formed around axons by the support cells present. In the peripheral nervous system, Schwann cells form the myelin sheath, whereas in the central nervous system it is a cell type known as a glial cell or oligodendrocyte.
Only one axon is myelinated by a single Schwann cell whereas a glial cell is capable of myelinating several axons at once. The function of the myelin sheath is insulation. As the protective plastic covering of an electrical wire speeds up the rate of an impulse along it, so the myelin sheath speeds up the conduction of the nerve impulse.

Formation of the sheath by the support cell is complex. The cell approaches the axon, the two outer membranes fuse then either the cell twists around the neuron many times, or else the neuron rotates, presently it is not know which of these occur. The result is a double membrane structure, which is rich in lipid. Neurons that do not require fast transmission remain non-myelinated. Between Schwann cells where myelination ends and another Schwann cell begins there is a small gap called the Node of Ranvier is formed.

White and Grey Matter

In the CNS some regions appear whitish, whilst others grey. These regions are referred to as **white matter** and **grey matter** respectively.
The whitish colour of **white matter** is derived from myelin, and white matter is composed of dendrites and myelinated and unmyelinated axons.
Grey matter contains cell bodies, dendrites, unmyelinated axons, axon terminals and neuroglia. It appears grey due to the absence of myelin and due to the Nissl bodies in the cell bodies.

Types of nerves

Sensory nerves
These nerves transmit impulses from sensory receptors, such as those sensitive to pain, temperature, pressure, or chemical and mechanical stimuli, **towards** the spinal cord of the Central Nervous System (CNS). These are referred to as **afferent** nerves, and are part of the Peripheral Nervous System.

Motor nerves
Conduct impulses **away** from the CNS directly towards the voluntary muscles of the body. They are referred to as **efferent**, and are also part of the Peripheral Nervous System.

Autonomic motor nerves
These nerves form a major part of the Autonomic Nervous System, therefore affecting the visceral organs and their walls. The neurons move out of the spinal cord (CNS) and first synapse with a second neuron within a ganglion before continuing on to influence the effector (smooth) muscle. These neurons are also part of the Peripheral Nervous System.

Interneurons
These neurons are commonly found in the CNS, and relay impulses between the incoming afferent neurons and the outgoing efferent neurons.

Nerve impulse (action potential)

Excitable cells communicate with each other by action potentials or graded potentials.
Action potentials allow communication over both short and long distances, whilst graded potentials allow communication over short distances only.

Production of both types of potentials relies upon the existence of a resting membrane potential and the presence of certain ion channels.
The **membrane potential** is an electrical voltage across the membrane.
Graded and action potentials occur because of **ion channels** in the membrane allow ion movement across the membrane that can change the membrane's potential.

Ion cannels

Ion channels are either gated or non-gated. Non-gated channels are always open, whilst gated channels open in response to some form of stimuli. Gated ion channels respond to voltage changes, chemicals or mechanical pressure.

Resting membrane potential

The resting membrane potential of a non-conductive neuron is positive outside and negative inside. The typical value for the resting membrane potential is -70mV, and the membrane is said to be polarised.

The resting membrane potential is determined by the unequal distribution of ions across the plasma membrane, and the selective permeability of the membrane to sodium (Na+) and potassium (K+) ions.
The sodium-potassium pumps maintain the potential by pumping the sodium out, as it slowly leaks back into the cell.

Action potential

The action potential is a series of rapidly occurring events which reverse the membrane potential depolarisation) and then restore it to the resting state (repolarisation).
Rapid opening of the voltage gated sodium channels causes depolarisation. If the depolarisation reaches threshold, the membrane potential reverses (i.e. the cell becomes positive).
The slower opening of voltage gated potassium channels

Nerve transmission

Neurons have two features that enable them to transmit information:

- **Excitable**- they can detect and respond to stimuli
- **Conductive**- they can carry a signal from one end to another

Neurons communicate either by **action potentials** or **graded potentials**. Graded potentials only allow local communication, whilst action potentials allow both local and long distance communication.

We shall be focussing upon action potentials, but you should also familiarise yourself with graded potentials, when reading upon the subject.

Resting membrane potential

The resting potential is the state of readiness that a neuron has, when it is ready to conduct impulses. In this state the axon membrane is **polarised**- the fluid inside of the cell is negatively charged compared to the fluid outside the membrane, due to an unequal distribution of ions. The difference in charge averages –70mV.
The resting potential is maintained by the selective permeability of the membranes' ion channels and the **sodium-potassium pump**.

- Sodium ions are pumped out, and potassium ions pumped in at the ratio of 3 sodium ions: 2 potassium ions.
- Whilst resting, passive sodium ion channels are closed, but passive potassium channels are open, allowing the potassium to diffuse out faster than sodium can diffuse in.

These mechanisms result in the polarisation of the cell, with positive ions accumulating outside the cell.

Action potential

An action potential (nerve impulse) is the temporary reversal of the resting potential that spreads rapidly along the axon.

When a stimulus reaches a neuron the sodium ion channels open, allowing the ions to move in. The ions move in slowly initially, changing the polarisation of the cell towards 0mV. At a threshold of about –50mV a rapid rush of ions is triggered and the inside of the cell becomes positive (about +40mV) relative to the outside. As the charge is reversed the membrane is termed **depolarised.** Depolarisation triggers the action potential.

If the stimulus does not result in the change of polarisation reaching the threshold then no action potential results. Action potentials are always of the same strength for a given neuron- there are no large or small action potentials. Therefore either the threshold is reached and a full action potential is triggered or the threshold is not reached and no action potential occurs.

When a section of axon membrane depolarises a local current is produced. This current stimulates the next section, resulting in depolarisation. In this way the action potential spreads sequentially along the axon away from the cell body.

After a brief period (about 1 millisecond) the potassium channels open, which allows potassium ions to rush out, reversing the depolarisation and also sodium ion channels close to re-establish resting potential.

Refractory period

The refractory period is the delay between two action potentials or between an action potential and the resting potential. It has two phases:

1. The **absolute refractory period**- the period immediately after the sodium channels close, during which no action potential can be conducted.
2. The **relative refractory period**- the period during which the membrane recovers and becomes increasingly responsive to stimuli. If a stimulus is particularly intense then another action potential can be triggered.

The refractory period serves to limit the frequency of action potentials, ensures that each action potential is separated from the next, and it ensures that an action potential goes in one direction only, as the depolarisation can only move away from areas undergoing a refractory period.

Speed of action potential

The speed of an action potential depends upon:

- **Axon diameter**- the larger the diameter the faster the conduction
- **Myelination**- an impulse travels faster in a myelinated neuron
- **Synapses**- the release of chemicals across synapses causes a brief time delay, therefore the more synapses the slower the conduction.

Saltatory conduction

As mentioned earlier, some cells are myelinated. The myelin insulates the axon like the plastic sheath surrounding copper electric cable. The gaps between the myelin are called the nodes of Ranvier. Action potentials that travel along a myelinated axon jump between these gaps by **salutatory conduction**.
Salutatory conduction has two advantages:

1. It increases greatly the speed of the conduction of a nerve impulse
2. It requires only the gaps to become depolarised, therefore the neuron expends less energy to restore the resting potential.

Synapses

Synapses are the functional junction between neurons or between a neuron and an effecter such as muscles or glands.
There are two types: **electrical** and **chemical**.

Electrical synapse

- Ionic current spreads directly from one cell to another
- Allow faster communication
- Can synchronise activities of groups of neurons or muscle fibres

Chemical synapse
The anatomy of a chemical synapse is covered above with the **axon**.

- One-way information transfer
- Releases neurotransmitters
- Neurotransmitters are either **excitatory** or **inhibitory**
- **Excitatory** neurotransmitters reduces polarity of postsynaptic membrane, bringing it closer to threshold and therefore action potential
- **Inhibitory** neurotransmitters increase polarity of postsynaptic membrane, therefore making the generation of an action potential more difficult

If enough excitatory neurotransmitter attaches to the postsynaptic membrane then an action potential is initiated in that cell. If the effect is the result of several action potentials it is termed **summation.**

Neurotransmitters

There are over 100 different recognised neurotransmitters. The main types of neurotransmitter are:

- **Acetylcholine**
- **Noradrenalin / norepinephrine**
- **Amino acids**
- **Biogenic amines**
- **Purines**
- **Nitric oxide**
- **Neuropeptides**

These are some examples of neurotransmitters and their principal action:

- Acetylcholine - voluntary movement of the muscles
- Norepinephrine - wakefulness or arousal
- Dopamine - voluntary movement and emotional arousal
- Serotonin - memory, emotions, wakefulness, sleep and temperature regulation
- GABA (gamma aminobutyric acid) - motor behaviour
- Glycine - spinal reflexes and motor behaviour
- Neuromodulators - sensory transmission-especially pain

Task:

Read further on how neurotransmitters work, where the different types are found and their characteristics.

Self-assessment questions

Chapter-8

1. Identify the pre and post-synaptic neurotransmitters found in:
    a) Somatic/voluntary nervous system
    b) Sympathetic nervous system
    c) Parasympathetic nervous system

2. Draw three different types of synapses and label the key components

3. Label the following plates:
    Plate-11