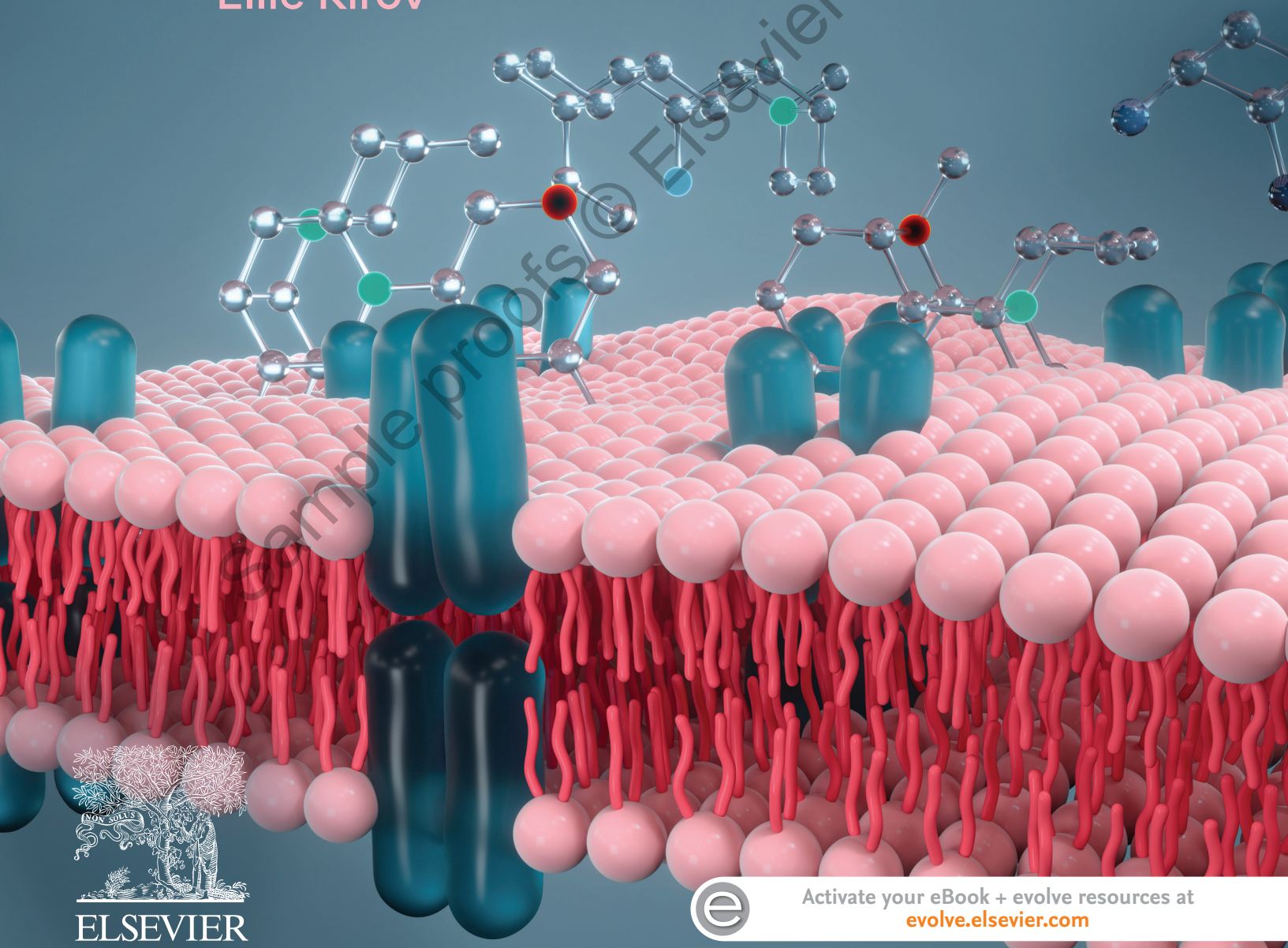
Herlihy's The Human Body in Health and Illness

Barbara Herlihy
Ellie Kirov

AUSTRALIA AND NEW ZEALAND EDITION



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Elsevier Australia. ACN 001 002 357
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Tower 1, 475 Victoria Avenue, Chatswood, NSW 2067

The Human Body in Health and Illness, Seventh edition

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ISBN: 978-0-323-71126-5

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Herlihy's The Human Body in Health and Illness, Australia and New Zealand edition
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ISBN: 978-0-7295-4372-9

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National Library of Australia Cataloguing-in-Publication Data

A catalogue record for this book is available from the National Library of Australia

Senior Content Strategist: Natalie Hunt
Content Project Manager: Kritika Kaushik
Edited by Margaret Trudgeon
Proofread by Tim Learner
Cover by Georgette Hall
Internal design: SD 36
Index by SPI Global
Typeset by GW Tech
Printed in Singapore by KHL

Last digit is the print number: 9 8 7 6 5 4 3 2 1

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Dedication

To those that inspire, motivate and pave the way for scientific investigation . . .

To those that strive, delve and thirst for knowledge and wisdom . . .

To those that search, enquire and express curiosity in phenomena unknown . . .

. . . to you, this book is warmly dedicated.

Dr Ellie Kirov

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Acknowledgements

The development and publication of an anatomy and physiology textbook for Australian and New Zealand students requires the combined efforts of many people, all of whom are talented, competent, highly professional and exceedingly understanding.

A special thank you to the staff of Elsevier Australia, in particular, Natalie Hunt, Kritika Kaushik and Sukanthi Sukumar for their expertise, support and patience during the writing and development process. You are a fantastic team to work with.

Many thanks to Margaret Trudgeon for her close attention to detail, profound editing skill and genuine approachability, and to the dedicated reviewers of the textbook who have provided valuable feedback and meaningful insight based on their diverse range of expertise.

Many thanks also to my colleagues in the School of Science at Edith Cowan University, Professor Ray Froend (Associate Dean, Science), who has expressed keen interest and support for this project; Associate Professor Justin Brown (Associate Dean, Teaching and Learning Science), who has provided a sterling example of academic integrity; and Dr Alan Needham, who has always been a fine mentor in the realm of academic science.

A final thankyou to all my nearest and dearest who have been so kind, patient and supportive. It was such a rewarding experience sharing thoughts and ideas during the development of the final product.

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Preface

Since the first US-based edition of *The Human Body in Health and Illness* was published in 2000, its success as a popular anatomy and physiology textbook has been cemented within foundational health science courses, leading to the release of five further editions in 2003, 2007, 2011, 2014 and 2018. These editions, while continuing to strengthen the textbook's popularity, also highlighted the need for a text that reflects current pedagogy within the Australia–Pacific region.

In this first Australian and New Zealand edition of *Herlihy's The Human Body in Health and Illness*, the textbook content has been contextualised for an Australian and New Zealand audience. The language, expressions, scientific terminology, pronunciation guides, real-world examples and relevant medications have been tailored to support a consistent approach to the study of foundational anatomy and physiology within care-focused courses. The organisation of body systems within and across chapters offers a straightforward format, while many updated images offering conceptual clarity have been incorporated into the content. These features provide a smoother transition towards more specialised anatomy and physiology content as learners progress through their course.

Herlihy's The Human Body in Health and Illness Australia and New Zealand edition offers the same outstanding content, but with user-friendly enhancements and regional relevance, making the text more accessible. It is anticipated that this approach will guide learners through the exciting journey of foundational anatomy and physiology studies, paving the way for exploration into more advanced health science courses and beyond.

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To the Instructor

Welcome to the first Australian and New Zealand edition of *Herlihy's The Human Body in Health and Illness*. It is hoped that this textbook will assist you in imparting valuable knowledge about the human body to students preparing for careers in the health professions.

Herlihy's The Human Body in Health and Illness provides a foundational background on the human body based on all of its parts and the way these parts work together. This knowledge is fundamental to the study of most health science disciplines and is constantly developing as the body continues to reveal its mysteries, and new discoveries come to light. It is hoped that you find as much enjoyment in imparting this knowledge as I do.

Herlihy's The Human Body in Health and Illness is a foundational anatomy and physiology textbook addressed to the student with an interest in entering the health professions. It is written for students who have minimal preparation in the sciences; no prior knowledge of biology, chemistry or physics is required. The textbook provides fundamental scientific information necessary for an understanding of anatomy and physiology.

The basic principles of chemistry and biochemistry are presented in Chapters 2 and 4, and these set the stage for an understanding of cellular function, fluid and electrolyte balance, endocrine function and digestion. Chapter 5, Microbiology and Infection, presents clinically relevant microbiological topics. Consider the cases of disease transmission, development and prevention; in particular, the link between puerperal fever and handwashing, which provides a historically interesting account corresponding to the current emphasis on hand hygiene and healthcare-associated infection.

Anatomy and physiology content is presented in a structurally hierarchical order, from simple to complex. The textbook begins with fundamental chemical concepts, continues to cellular structure and progresses through the various organ systems. Two key themes are evident throughout the textbook: (1) the relationship between structure and function—the student must understand that an organ is anatomically designed to perform a specific physiological function; and (2) homeostasis—the role that each organ system plays in sustaining life and what happens when that delicate balance is disturbed.

The textbook addresses two common issues associated with the provision of relevant anatomy and physiology content. The first issue relates to the amount of content. The field of anatomy and physiology is vast; therefore, there must be a selection of content that can be mastered in the short period of time such as one or two semesters. This textbook focuses on the physiology that is basic and most clinically relevant. Pathophysiology is introduced primarily to clarify physiological function. For example, the different types of anaemias illustrate the various steps in the production of red blood cells. The second issue relates to the purpose for incorporating physiology. While this textbook is not designed for preparing physiologists, it is important for students to be able to apply physiology concepts to understand clinically relevant content such as pathophysiology, physical assessment, diagnostics and pharmacology. An understanding of physiology is crucial for advancement in the medically related sciences.

TEXTBOOK STRENGTHS

- Anatomy and physiology are clearly and simply explained. A full colour set of carefully selected illustrations, diagrams and additional reference tables support the textbook.
- Clearly numbered chapter subheadings provide a breakdown of content. This allows for specific content areas to be prescribed as reading or considered gradually in a step-by-step form.
- The textbook integrates pathophysiology, and is used primarily to amplify normal anatomy and physiology. The expanded Medical Terminology and Disorders tables and frequent references to common medical terminology allow the textbook to be used for an introductory course in pathophysiology and medical science.
- In addition to pathophysiology, other concepts are integrated throughout the textbook. These include common diagnostic procedures such as blood count, lumbar puncture, urinalysis and electrocardiography. Pharmacological topics are also introduced and, like pathophysiology, are used to amplify normal anatomy and physiology. For example, the discussion of the neuromuscular junction is enhanced by a description of the effects of neuromuscular blocking agents. Due to the effort of the textbook to make clinical correlations, it sets the stage for more advanced health science courses,

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including pharmacology and medical–surgical nursing.
- Checkpoint boxes are distributed throughout each chapter and encourage students to master that content before progressing through the chapter.
- Focus on Physiology boxes provide selected clinically relevant topics that are too advanced to be included in the textbook as foundational information. These features contain advanced physiological content commonly used in the clinical setting and allow instructors to scale their coverage in a manner appropriate to the course. They offer students the opportunity to make further connections between the foundational content presented and the application of more advanced clinical concepts. (See 'To the Student' on page xi for descriptions and examples of each of the chapter features.)
- Medical terminology is introduced, defined and used throughout the textbook. Common clinical terms, such as hyperkalaemia, vasodilation, hypertension and diagnosis are defined and reused so that the student gradually builds a substantial medical vocabulary. The expanded Medical Terminology and Disorders tables are provided to maximise the use of common medical terms and disorders. To help foster a broader understanding of medical terminology, word parts and their meanings are included for nearly every term presented. Repetition of these terms helps students gain greater understanding of the specific medical language they will be learning to use for a future in the health professions. A description is also provided which gives the definition or other pertinent information on the topic.
- The Review Your Knowledge section has been expanded to include questions that require an analytical response. The Figure Review questions are based on interpretation of information provided in the chapter figures. The questions can only be answered by analysing the figures and/or information presented in the tables. This exercise encourages students to pay closer attention to the concepts presented in the figures and tables. It is important to encourage students to see that the concepts provided in the figures and the textbook are conveying the same message.
- The textbook is supported by many activities, exercises, puzzles, games, colouring activities, animations, practice chapter exams, and word-part multiple choice questions on Evolve (http://evolve.elsevier.com/AU/Kirov/Herlihy). These activities emphasise the focus of this textbook, which is clinically relevant anatomy and physiology.
- The textbook incorporates many interesting anecdotes from the history of medicine. Although the human body is perfectly organised and predictable, experiences from the past provide an insight into knowledge progression, and how this has influenced modern medical understanding and procedures.

CLASSROOM RESOURCES

Materials from the Study Guide and Evolve Instructor Learning Resources can be used to support students:
- who are having difficulty in grasping the content
- who have missed class(es)
- engaged in pathophysiology and pharmacology, who may require revision of physiology concepts.

STUDY GUIDE

Herlihy's The Human Body in Health and Illness – Study Guide Australia and New Zealand edition offers students at all levels of learning the opportunity to test their knowledge further, and is a ready-made resource for instructors seeking to assign homework or revision activities. Each chapter includes two parts: Part I, Mastering the Basics, with matching, ordering, colour and drawing, diagram examination, table completion, filling in the blanks, and determining similars and dissimilars; and Part II, Putting It All Together, containing multiple choice questions, case studies and word puzzles. Textbook chapter section references are included with the questions, and the answer key is available on the Evolve website to instructors.

EVOLVE INSTRUCTOR LEARNING RESOURCES

The Evolve website for *Herlihy's The Human Body in Health and Illness* (http://evolve.elsevier.com/AU/Kirov/Herlihy) includes all of the Student Resources, as well as the following Instructor Resources:
- Power Point Slides
- Textbook Image Collection
- Audience Response System Questions
- Instructor's Chapter Exams
- Answer Key to the Study Guide

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To the Student

Welcome to the first Australian and New Zealand edition of *Herlihy's The Human Body in Health and Illness*. It is hoped that this textbook will serve you well on your journey into the health professions. It is an exciting journey and we wish you all the best.

This textbook will take you on an amazing journey through the human body. You will learn about many body parts and structures and, more importantly, how they work in an integrated manner to sustain normal functioning and life. This information will be useful in clinical practice when patients present with disorders of those structures. The following special features were created to help make learning memorable and enjoyable.

TEXTBOOK FEATURES

KEY TERMS

Key terms are listed at the beginning of each chapter, along with a page reference. Each is:

- presented in the textbook in blue print
- accompanied by a pronunciation guide
- thoroughly explained within the chapter
- defined in the glossary.

OBJECTIVES

Numbered objectives identify the goals for each chapter.

ILLUSTRATIONS

Full colour illustrations and diagrams help you make sense of anatomy and physiology using clarity and insight.

POINT OF INTEREST

These boxed and informative vignettes refer to clinical situations, interesting and relevant historical events and biological comparisons related to anatomy and physiology.

FOCUS ON PHYSIOLOGY

These boxed features challenge you with more advanced anatomy and physiology concepts.

CHECKPOINT

These questions are distributed throughout the chapter to help reinforce important concepts.

SPOTLIGHT ON AGEING

These boxed features contain numbered lists describing how the ageing process affects the anatomy and physiology of human organ systems.

CONCEPT OVERVIEW

These boxed features appear regularly throughout the chapters and help you summarise and synthesise key concepts.

MEDICAL TERMINOLOGY AND DISORDERS TABLES

These tables describe medical terms and specific disorders related to individual body systems, with a focus on developing a strong working medical vocabulary, which is necessary for a career in the health professions.

END-OF-CHAPTER FEATURES

Summary Outline

A detailed outline at the end of each chapter summarises key concepts and serves as a concise review of the chapter content. It is best used as a study tool to review your reading and prepare for assessment.

Review Your Knowledge

The matching and multiple choice questions in this section cover the major points of the chapter and allow you to test your comprehension.

Figure Review

This review section asks you to interpret the figures in the chapter and reinforces the importance of the concepts presented.

ANSWERS TO REVIEW YOUR KNOWLEDGE AND FIGURE REVIEW QUESTIONS

The **Appendix** contains answers to all Review Your Knowledge and Figure Review questions found in the textbook.

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GLOSSARY

The glossary includes a pronunciation guide and a brief definition of all key terms and many other words in the textbook.

STUDY GUIDE

Enhance your learning of the textbook content with the accompanying *Herlihy's The Human Body in Health and Illness – Study Guide Australia and New Zealand edition*. The Study Guide offers students at all levels of learning the opportunity to test their knowledge further, from labelling and colouring exercises, to multiple choice practice tests and case studies.

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Nervous System: Nervous Tissue and the Brain

10

Objectives

1. Define the two divisions of the nervous system.
2. List three general functions of the nervous system.
3. Discuss the cellular composition of the nervous system.
4. Compare the structure and functions of the neuroglia and neurons.
5. Explain the function of the myelin sheath.
6. Explain how a neuron transmits information.
7. Describe the structure and function of a synapse.
8. Describe the functions of the four major areas of the brain and the four lobes of the cerebrum.
9. Describe how the skull, meninges, cerebrospinal fluid and blood–brain barrier protect the central nervous system.

Key Terms

action potential: (p. 187)
association areas: (p. 197)
axon: (p. 186)
blood–brain barrier: (p. 185)
brain: (p. 183)
brain stem: (p. 198)
central nervous system (CNS): (p. 183)
cerebellum: (p. 199)
cerebrospinal fluid (CSF): (p. 201)
cerebrum: (p. 193)
choroid plexus: (p. 202)
convolution: (p. 194)
corpus callosum: (p. 193)
dendrite: (p. 186)
depolarise: (p. 187)
fissure: (p. 194)
frontal lobe: (p. 195)
ganglion: (p. 187)
gyrus: (p. 194)
hypothalamus: (p. 197)
interneuron: (p. 186)
limbic system: (p. 199)
medulla oblongata: (p. 198)
meninges: (p. 201)
myelin sheath: (p. 186)
neuroglia: (p. 185)
neuron: (p. 185)
neurotransmitters: (p. 191)
nodes of Ranvier: (p. 186)
occipital lobe: (p. 196)
parietal lobe: (p. 195)
peripheral nervous system (PNS): (p. 183)
repolarise: (p. 187)
resting membrane potential: (p. 188)
reticular formation: (p. 199)
subarachnoid space: (p. 201)
sulcus: (p. 194)
synapse: (p. 190)
temporal lobe: (p. 196)
thalamus: (p. 197)
threshold potential: (p. 187)

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Thinking, feeling, moving, seeing, hearing, responding, planning, remembering, being aware of environmental cues, and so much more, are functions performed by the nervous system. Extensive networks of specialised cells are interconnected to provide the body with a complex and integrated telecommunications network.

10.1 THE NERVOUS SYSTEM: STRUCTURE AND FUNCTION

DIVISIONS OF THE NERVOUS SYSTEM

The structures of the nervous system are divided into two parts: the central nervous system and the peripheral nervous system. The **central nervous system (CNS)** includes the **brain** and the spinal cord. The CNS is located in the dorsal cavity. The brain is located in the cranial cavity; the spinal cord is enclosed in the spinal cavity. The **peripheral nervous system (PNS)** is located outside the CNS and consists of the nerves that connect the CNS with the rest of the body (Fig. 10.1).

FUNCTIONS OF THE NERVOUS SYSTEM

The nervous system performs three general functions: a sensory function, an integrative function and a motor function (Fig. 10.2).

SENSORY FUNCTION

Sensory nerves (afferent pathways) gather information from inside the body and from the outside environment. The nerves then carry the information towards the CNS where they are transmitted to the brain via the spinal cord.

INTEGRATIVE FUNCTION

Sensory information brought to the CNS is interpreted. The brain gathers information about the

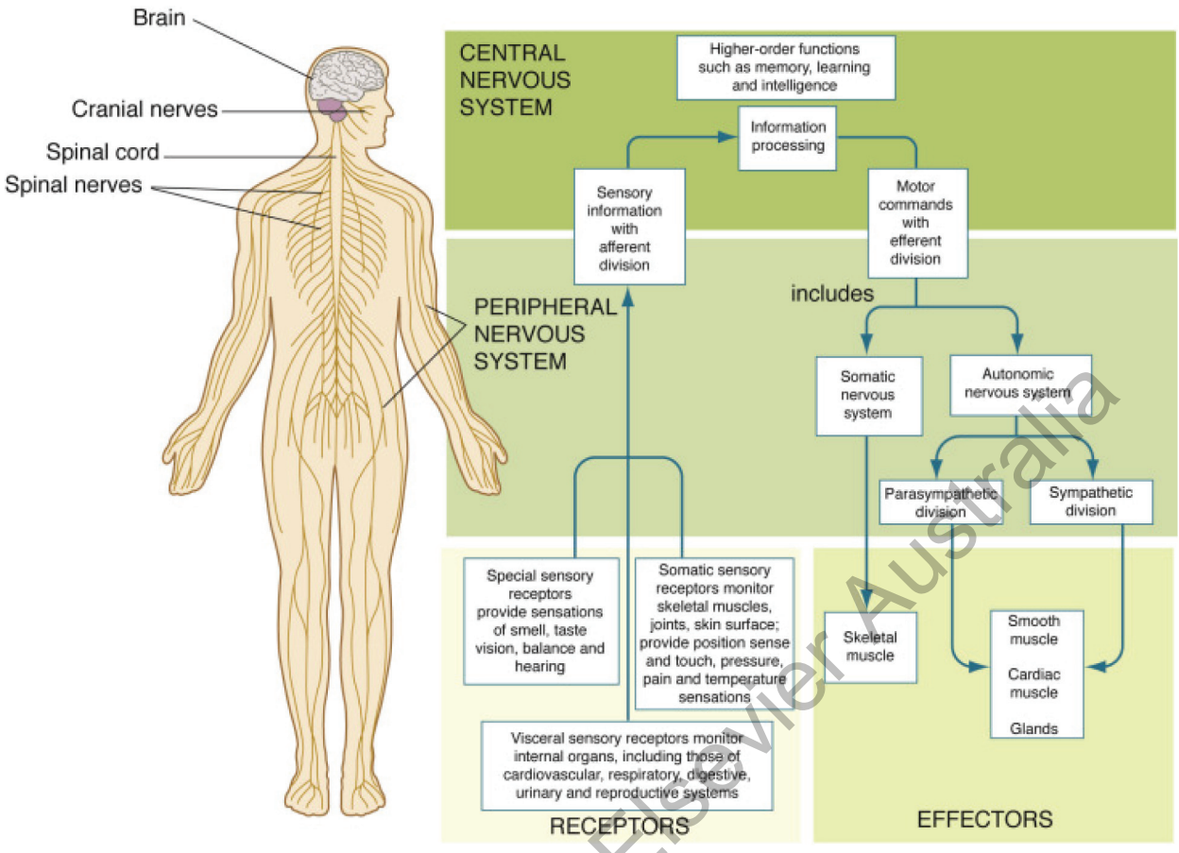

Fig. 10.1 The Functional Divisions of the Nervous System. The central nervous system, peripheral nervous system and functional pathways. (L Aitken, A Marshall, W Chaboyer 2019. Critical Care Nursing, 4th edn. Elsevier Australia, Chatswood. Fig. 16.1.)

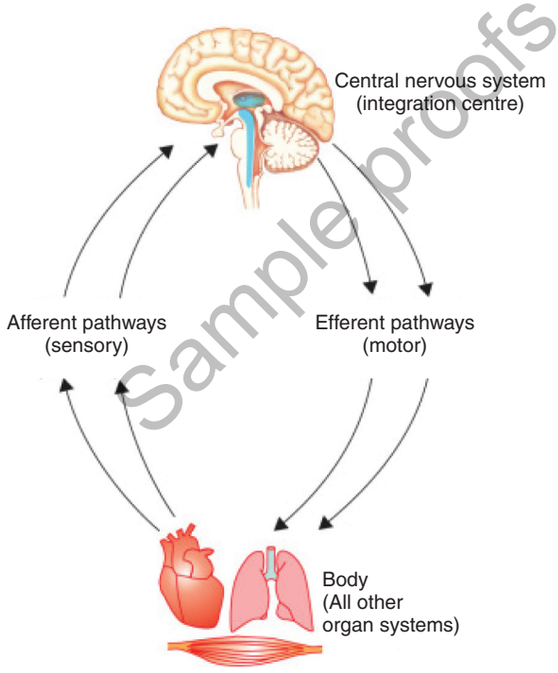

Fig. 10.2 Main Functions of the Nervous System. Sensory function via afferent pathways, integrated centrally at the central nervous system, leading to motor function via efferent pathways throughout the body. (J Craft, C Gordon et al 2019. Understanding Pathophysiology ANZ, 3rd edn. Elsevier, Chatswood. Fig. 6.2.)

situation, recalls past experiences relating to similar situations and determines a response. The brain integrates, or puts together, everything it knows about the situation and then makes a plan.

MOTOR FUNCTION

Motor nerves (efferent pathways) convey information away from the CNS towards the muscles and glands of the body. Motor nerves carry out the plans made by the CNS and convert the plan into action.

Checkpoint

1. State the two divisions of the nervous system.
2. Differentiate between sensory, integrative and motor function; provide an example of each.

10.2 CELLS OF THE NERVOUS SYSTEM

Nervous tissue is composed of two types of cells: the neuroglia and the neurons.

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NEUROGLIA

Neuroglia (new-ROHG-lee-ah), or glial cells, are the nerve glue. Neuroglia are the most abundant of the nerve cells; most glial cells are located in the CNS. Glial cells support, protect, insulate, nourish and generally care for the delicate neurons. Some of the glial cells participate in phagocytosis; others assist in the secretion of cerebrospinal fluid. Glial cells, however, do not conduct nerve impulses.

Some of the common glial cells are the astrocytes, microglial cells, ependymal cells and oligodendrocytes (Fig. 10.3). The star-shaped *astrocytes* (ASS-troh-sytes) are the most abundant of the glial cells and have the most diverse functions; they support the neurons structurally, cover the entire surface of the brain and help form a protective barrier, called the **blood–brain barrier**. Astrocytes maintain the blood–brain barrier by attaching their large, flat feet to the surface of brain capillaries. This barrier helps prevent toxic substances in the blood from entering the nervous tissue of the brain and spinal cord. Astrocytes also secrete nerve growth factors that promote neuron growth and enhance synaptic development. Microglial cells form the immune defence in the CNS and actively pursue and phagocytose foreign substances. *Ependymal* (eh-PEN-di-mal) cells form sheets that line the fluid cavities in the CNS and assist in the formation of cerebrospinal fluid. Their cilia help to circulate cerebrospinal fluid. Oligodendrocytes form myelin around CNS neurons. The glial cells are listed in Table 10.1. Since glial cells undergo mitosis, most primary CNS tumours are composed of glial cells, such as astrocytomas, which are tumours composed of astrocytes.

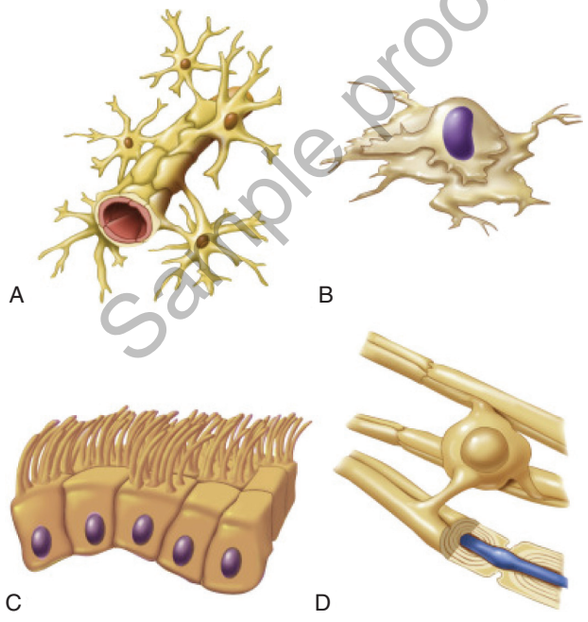

Fig. 10.3 Types of Neuroglial Cells. (A) Astrocytes. **(B)** Microglial cell. **(C)** Ependymal cells. **(D)** Oligodendrocyte. (KT Patton et al 2012. Essentials of Anatomy and Physiology, 9th edn. Mosby Elsevier, St Louis.)

Table 10.1 Types of Neuroglia

CELL NAME	FUNCTION
Astrocytes	Star-shaped cells present in blood–brain barrier; also anchor or bind blood vessels to nerves for support, act as phagocytes and secrete nerve growth factors
Ependymal cells	Line the ventricles as part of the choroid plexus; involved in the formation of cerebrospinal fluid
Microglia	Protective role; phagocytosis of pathogens and damaged tissue
Schwann cells	Produce myelin sheath for neurons in the peripheral nervous system; assist in regeneration of damaged nerve fibres
Oligodendrocytes	Produce myelin sheath for neurons in the central nervous system

Point of Interest

Polio Virus and Brain Cancer

Many years ago, poliomyelitis, an infection caused by poliovirus, was terrifying because it often resulted in life-long severe paralysis (infantile paralysis). Recently, however, the poliovirus has been modified by scientists in a way that not only prevents its ability to cause poliomyelitis but enables it to be used in the treatment of glioblastoma, a common and lethal type of brain cancer. The link between the modified poliomyelitis virus and brain cancer cells is simple. Cancer cells often surround themselves with a protective shield that covers their surface antigens and protects them from the host's immune system. When injected, the modified poliovirus removes the shield surrounding the cancer cells, thereby exposing their surface antigens. The immune system of the host recognises the antigens as foreign, mounts an immune attack against the cancer cells and destroys the tumour. The result of this therapy is both encouraging and enlightening. It offers hope for a cure and also sheds light on the role of the immune system in cancer biology.

NEURONS

The second type of cell within the nervous system is the neuron. The **neuron** (NEW-ron) is the most important in the transmission of electrical signals. The neuron enables the nervous system to act as a vast communication network. Neurons have many shapes and sizes. Some neurons are extremely short; others are very long, with some measuring 1 metre in length. Unlike glial cells, neurons are amitotic (they lose their ability to undergo cell division or mitosis) and therefore do not replicate or replace themselves when injured. Since they are amitotic, neurons generally do not give rise to primary malignant brain tumours.

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As indicated in Fig. 10.2, neurons are functionally classified as follows:

- Sensory neurons: carry information to the CNS.
- Motor neurons: carry information away from the CNS.
- **Interneurons**: found only in the CNS. They form connections between sensory and motor neurons within the CNS. They play an important role in integrating all sensory information and the appropriate motor responses (not shown).

PARTS OF A NEURON

The main parts of the neuron are the dendrites, cell body and axon (Fig. 10.4).

- **Dendrites** (DEN-drytes) are tree-like structures that receive signals from other neurons and then transmit the signals towards the cell body. One neuron may have thousands of dendrites, whereas other neurons have fewer dendrites. The neuron with the greater number of dendrites can receive signals from many other neurons.
- The cell body contains the nucleus and is essential for the life of the cell. The cell body usually receives thousands of signals from the dendrites and determines the signal it wants to send to the axon.
- The **axon** (AK-son) is a long extension that transmits signals away from the cell body. The end of the axon undergoes extensive branching to form many axon terminals; it is within the axon terminals that the chemical neurotransmitters are stored. The arrow in Fig. 10.4 indicates the direction in which signal travels over the neuron: from dendrites to cell body to axon, essentially away from the cell body.

THE AXON

An enlarged view of the axon shows several unique structures: the myelin sheath, the neurilemma and the **nodes of Ranvier** (Fig. 10.4). Most long nerve fibres of both the peripheral and the central nervous systems are encased by a layer of white fatty material called the **myelin sheath** (MY-eh-lin SHEE-th). Myelin protects and insulates the axon. Nerve fibres covered by myelin are said to be myelinated. Some neurons are not encased in myelin and are called *unmyelinated neurons*. Myelination begins during the fourth month of fetal life and continues into the teenage years. As some axons of immature motor neurons lack myelination, the movements of an infant are slower and less coordinated than those of an older child. Severely restricting the fat intake of an infant or young child is unwise, because the child is still laying down myelin.

The formation of myelin sheath differs in the peripheral and central nervous systems. Surrounding the axon of a neuron in the peripheral nervous system is a layer of special cells called *Schwann cells* (sh-WON sels). The Schwann cells form the myelin sheath that surrounds the axon. The nuclei and cytoplasm of the Schwann cells lie outside the myelin sheath and are called the

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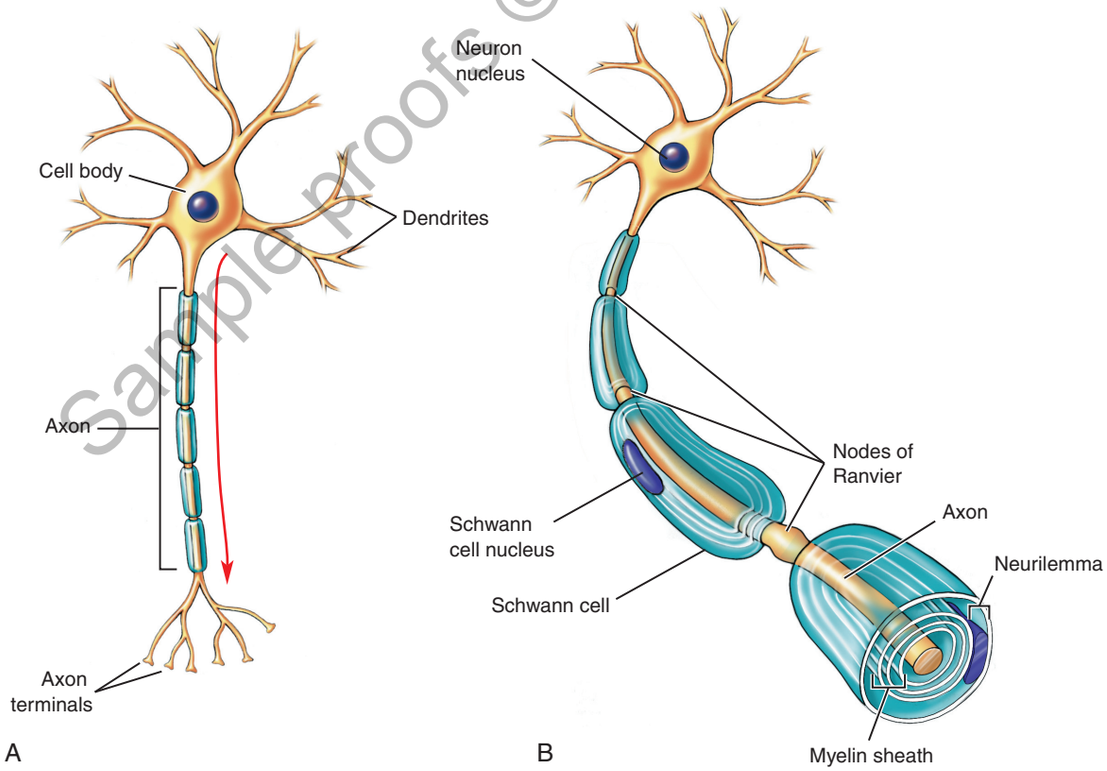

Fig. 10.4 Structure of a Neuron. (A) Dendrites, cell body, axon and axon terminals. **(B)** Structures associated with the axon. Myelin sheath, nodes of Ranvier and the neurilemma.

neurilemma (NUR-ih-LEM-uh). The neurilemma is important in the regeneration of a severed nerve.

In the CNS, the myelin sheath is formed not by Schwann cells but by *oligodendrocytes* (ohl-i-go-DEN-droh-sytes), a type of glial cell (Table 10.1). As there are no Schwann cells, there is no neurilemma. The lack of the neurilemma surrounding the axons accounts, in part, for the inability of the CNS neurons to regenerate. Failure of the neurons of the CNS to regenerate, however, is not fully explained by the lack of neurilemma; other factors include the formation of scar tissue and the lack of critical nerve growth factors.

Nodes of Ranvier, axonal areas not covered by myelin, appear at regular intervals along the myelinated axon.

Checkpoint

1. What is the biggest functional difference between glial cells and the neuron?
2. List the three main parts of a neuron.
3. What are the nodes of Ranvier?

WHITE MATTER AND GREY MATTER

The tissue of the CNS is white or grey. White matter is white because of the myelinated axons, whereas grey matter is made up of unmyelinated axons, cell bodies, interneurons and synapses.

Sometimes cell bodies appear in small clusters and are given special names. Clusters of cell bodies located in the CNS are generally referred to as *nuclei*. Small clusters of cell bodies in the peripheral nervous system are called *ganglia* (sing., **ganglion**). For example, patches of grey called the *basal nuclei* are located in the brain. Sometimes, these patches of grey are called *basal ganglia*, despite their location in the CNS.

Concept Overview

The nervous system plays a crucial role in allowing us to interact with our environment, both internally and externally. The nervous system has two divisions: the central nervous system and the peripheral nervous system. The nervous system performs three major functions: sensory, integrative and motor. There are two types of cells in the nervous system: the neuroglia and the neurons. The neuron is responsible for the rapid communication of electrical signals. The main parts of the neuron are the dendrites, cell body and axon. The nodes of Ranvier are well-spaced, unmyelinated areas along the axon.

10.3 NEURONS TRANSMITTING INFORMATION

Neurons allow the nervous system to convey information rapidly from one part of the body to the next. A stubbed toe makes itself known almost immediately. Consider how fast the information travels from your toe, where the injury occurs, to your brain, where the injury is interpreted as pain. Information is carried along the neuron in the form of a nerve impulse.

THE NERVE IMPULSE

The nerve impulse is an electrical signal that conveys information along a neuron. The nerve impulse is called the **action potential**. Follow Fig. 10.5 through the events of the action potential, from its resting state (resting membrane potential) to repolarisation.

- **Resting membrane potential** refers to the electrical charge difference across the membrane of the resting neuron. The inside of a resting neuron is more negative (–) than the outside (+). The resting cell is said to be polarised as charge differences exist on either side of the neural membrane, creating polarity. As long as the neuron is polarised, no nerve impulse is being transmitted. The cell is quiet or resting.
- *Depolarisation*. When the neuronal membrane is stimulated, a change occurs in the cell's electrical state. In the resting (polarised) state, the inside of the cell is negative. When the cell membrane is stimulated, the inside becomes positive. As the inside of the cell changes from negative to positive, it is said to **depolarise** (dee-POH-lar-ize), as the resting membrane polarity has reversed.
- *Repolarisation*. Very quickly, however, the inside of the cell again becomes negative. It returns to its resting state, or **repolarises** (ree-POH-lar-izes), so that the resting membrane polarity is restored. Unless the cell repolarises, it cannot be stimulated again.

Fig. 10.6 shows a recording of an action potential. Note the negative –70 millivolt (mV) reading inside the unstimulated neuron (resting membrane potential). When stimulated, the cell depolarises, that is, the inside of the cell becomes positive (+30 mV). Immediately, the cell repolarises; that is, the inside of the cell returns to its (–) resting membrane potential. Also shown is the threshold potential. The **threshold potential** is the degree of depolarisation (–55 mV) that must be attained for the neuron to completely fully depolarise to +30 mV. If threshold potential is not achieved by the stimulus, the signal decays, and the cell returns to the resting membrane potential. Under this condition the action potential fails to fire. Similarly, the action potential occurs via an *all-or-none phenomenon*, where it either occurs or does not occur at all. This is based on whether the action potential is propagated along the length of the axon, rather than whether an action potential has occurred.

Checkpoint

1. What is the meaning of the resting membrane potential, polarisation, depolarisation and repolarisation?
2. Describe the relationship of the threshold potential to the action potential.

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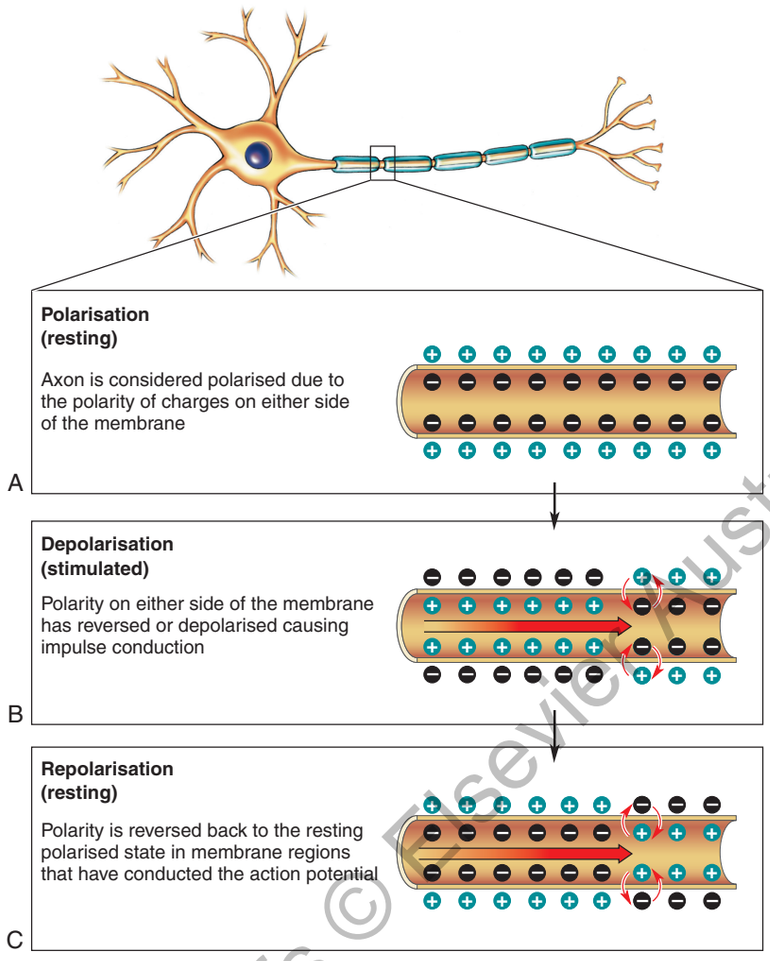

Fig. 10.5 Events of a Nerve Impulse (Action Potential). (A) Polarisation. **(B)** Depolarisation. **(C)** Repolarisation.

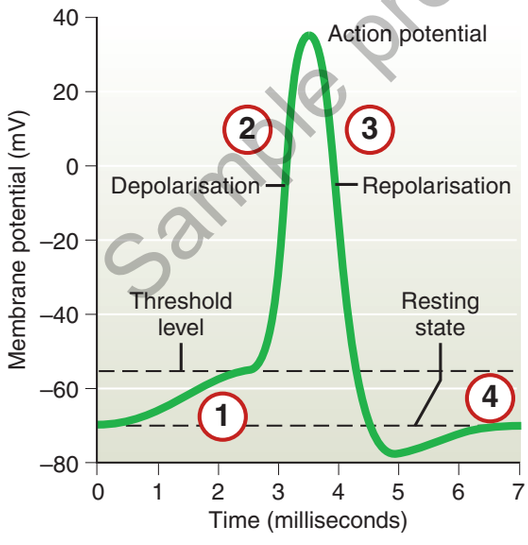

Fig. 10.6 Recording of an Action Potential. (1) Resting membrane potential (−70 mV) with threshold potential (−55 mV). **(2)** Depolarisation with action potential (+30 mV). **(3)** Repolarisation with hyperpolarisation (−75 mV). (EP Solomon 2016. Introduction to Human Anatomy and Physiology, 4th edn. Elsevier, Maryland Heights. Fig. 6-4.)

STAGES OF A NERVE IMPULSE

The changes associated with the action potential, or nerve impulse, are caused by the movement of specific ions across the cell membrane of the neuron. This is called the ionic basis of the action potential. To understand the diffusion of ions across the axonal membrane, you must remember the following: the chief intracellular cation is potassium (K^+) and the chief extracellular cation is sodium (Na^+). If the membrane becomes permeable to K^+, it diffuses outwardly. If the membrane is permeable to Na^+, it diffuses inwardly. The flow of ions is thus dependent on two factors: the concentration gradients of K^+ and Na^+ and the permeability characteristics of the membrane. Follow the movement of the ions in Fig. 10.7.

RESTING MEMBRANE POTENTIAL

In the resting state, the inside of the neuron is more negative than the outside. The resting state is the result of the numbers and types of ions, both positive (cations) and negative (anions), located inside the neuron.

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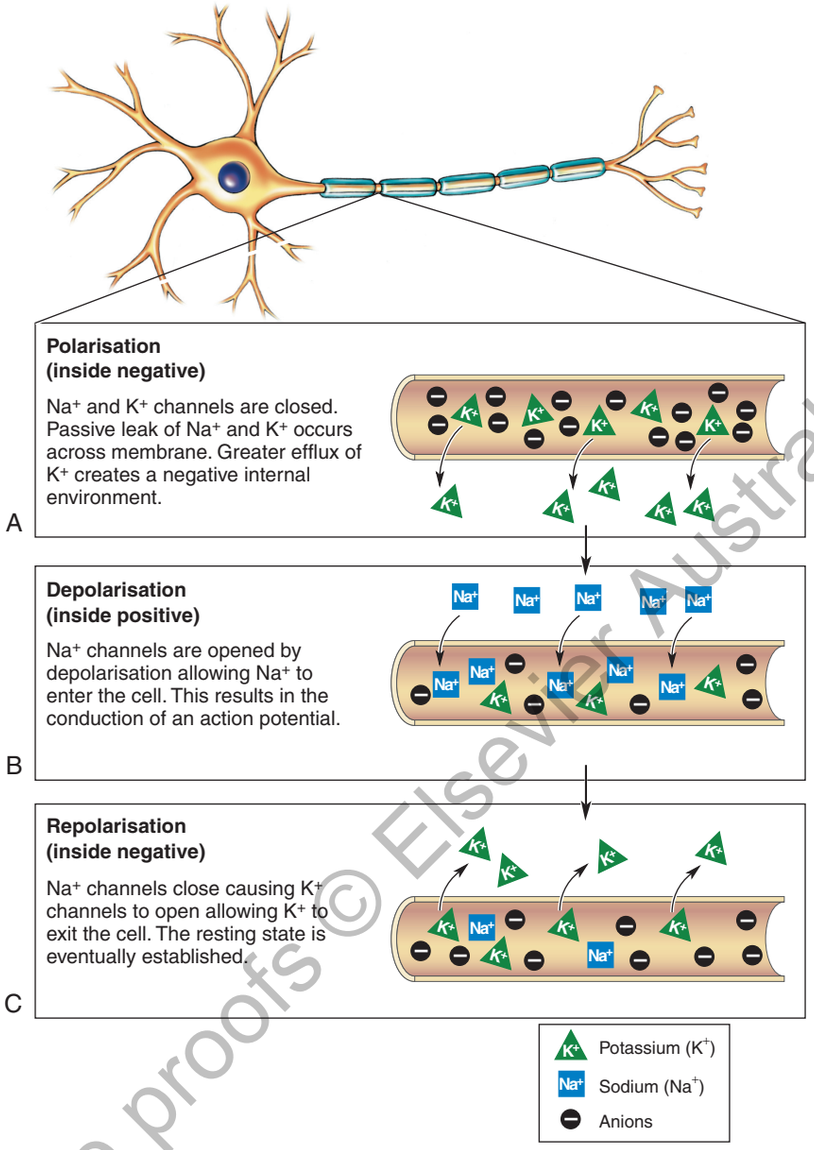

Fig. 10.7 **The Ionic Basis of the Nerve Impulse. (A)** Polarisation. **(B)** Depolarisation. **(C)** Repolarisation.

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These ions need to get into the cell in high concentrations. As such, they are pumped in by ATP-driven pumps in the cell membrane. The chief intracellular cation is K^+. In the resting state, however, some of the K^+ ions leak out of the cell, taking with them the positive charge. The lost positive charge and the excess anions trapped in the cell make the inside of the cell negative (–90 mV). It is the outward leak of K^+ that is responsible for the resting membrane potential.

DEPOLARISATION

The interior of the cell becomes positive when stimulated. When the neuron is stimulated, the permeability of the neuronal membrane changes in a way that allows sodium ions (Na^+) to diffuse rapidly across the membrane into the cell, carrying with it a positive (+) charge. Thus, it is the rapid inward diffusion of Na^+ that causes depolarisation.

REPOLARISATION

Following depolarisation, the inside of the cell quickly returns to its resting state and the neuronal membrane undergoes repolarisation. The change in the membrane permeability does two things: (1) it stops additional diffusion of Na^+ into the cell; and (2) it allows K^+ to rapidly diffuse out of the cell. The outward diffusion of K^+ decreases the positive charge from the inside of the cell, leaving behind the negatively charged anions. Thus, the outward movement of K^+ causes repolarisation and a return to the resting state.

Eventually, membrane pumps restore intracellular ion concentrations; Na^+ is pumped out of the cell,

while K^+ is pumped into the cell. Note that the repolarising phase of the nerve impulse is not caused by the active transport pumps. Repolarisation is caused by the rapid outward diffusion of K^+.

Checkpoint

1. What is the ionic basis of the resting membrane potential (polarisation)?
2. What is the ionic basis of depolarisation?
3. What is the ionic basis of repolarisation?

MOVEMENT OF THE NERVE IMPULSE

To convey information, a nerve impulse (action potential) must move the length of the neuron, from the cell body to the axon terminal. Fig. 10.8 shows that when nerve impulse 1 (NI-1) forms at point A, it also depolarises the next segment of the membrane (point B), causing nerve impulse 2 (NI-2) to form. Nerve impulse 2 then depolarises the next segment of the membrane at point C, causing the formation of nerve impulse 3 (NI-3).

Due to the ability of each nerve impulse to depolarise the adjacent membrane, the nerve impulse moves towards the axon terminal much like a wave. Note also in Fig. 10.8 that the height or amplitude of each nerve impulse along the axon is the same. This is important because it ensures that the nerve impulse does not weaken as it travels the length of a long axon.

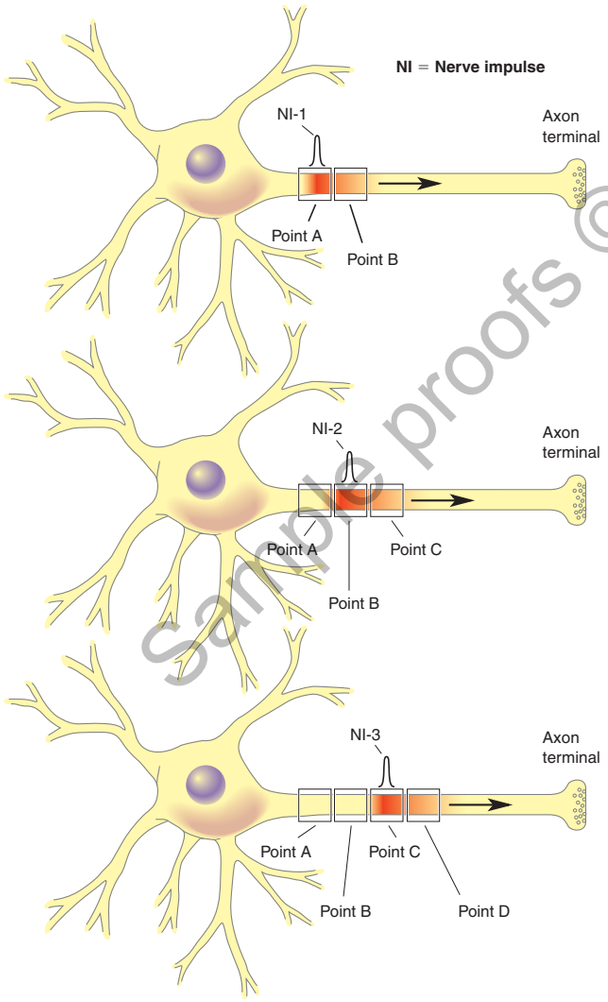

Fig. 10.8 Movement of the Nerve Impulse from the Cell Body to the Axon Terminals.

SPEED OF THE NERVE IMPULSE

Nerve impulses move very quickly. Myelination increases the movement of the nerve impulse along the axonal membrane. Recall that the axons of most nerve fibres are wrapped in myelin, a fatty material. At the nodes of Ranvier, the axonal membrane is bare or unmyelinated.

The nerve impulse arrives at the axon from the cell body but cannot develop on any part of the membrane covered with myelin. The nerve impulse can, however, develop at the nodes of Ranvier, the bare axonal membrane. Thus, in a myelinated fibre, the nerve impulse jumps from node to node to the end of the axon (Fig. 10.9). This jumping from node to node is called *saltatory conduction* (from the Latin word *saltare*, meaning 'to leap'). Saltatory conduction increases the speed with which the nerve impulse travels along the nerve fibre. For this reason, myelinated fibres are considered fast-conducting nerve fibres.

Checkpoint

1. What is the function of the nodes of Ranvier?
2. Explain how myelination and the nodes of Ranvier affect the rate of nerve impulse (action potential) conduction.

10.4 SYNAPSE ACROSS NEURONS

The nerve impulse travels the length of the axon. However, the signal does not jump from one neuron to the next. A **synapse** (sye-NAPS) helps information move chemically from one neuron to the next.

PARTS OF A SYNAPSE

Follow Fig. 10.10 as the synaptic structures in the following list are described.

- *Synaptic cleft*. The synaptic cleft is a space much like the neuromuscular junction (see Chapter 9 for a description of the neuromuscular junction). The space exists because the axon terminal of neuron A (presynaptic neuron) does not physically touch the dendrite of neuron B (postsynaptic neuron).
- *Receptors*. The dendrite of neuron B contains receptor sites. Receptor sites are locations on the cell membrane to which neurotransmitters bind. For example,

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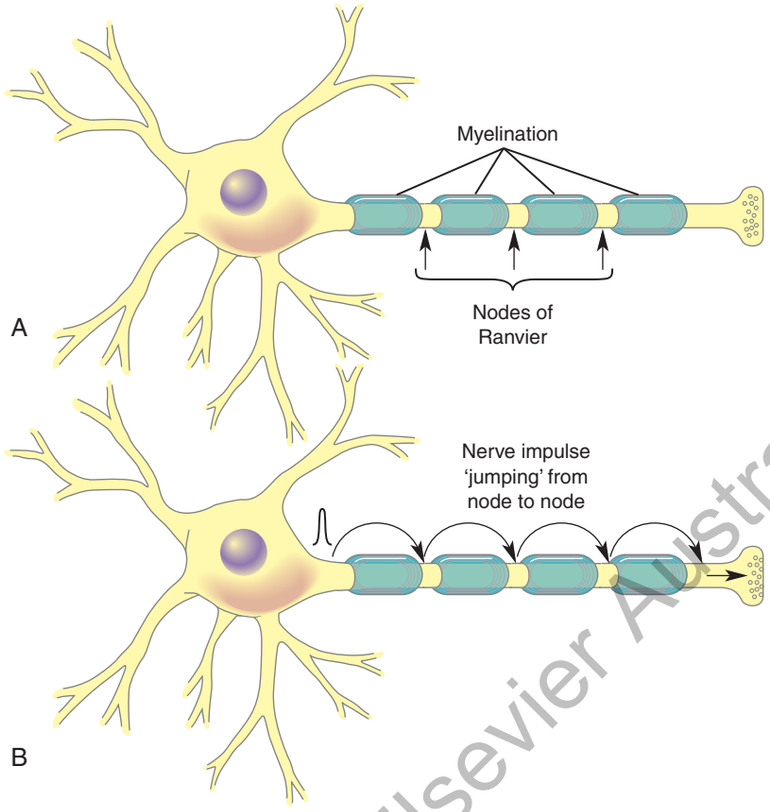

Fig. 10.9 Saltatory Conduction. (A) A myelinated axon and the nodes of Ranvier. **(B)** The nerve impulse jumps from node to node towards the axon terminal.

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acetylcholine (ACh) binds to the receptors on dendrite B. Each receptor site has a specific shape and accepts only those neurotransmitters that fit its shape.

- *Neurotransmitters*. The axon terminal of neuron A contains thousands of tiny vesicles that store liquid chemical substances called **neurotransmitters** (new-roh-TRANS-mit-ers). The most common neurotransmitters are ACh and noradrenaline (NA). Other CNS transmitters include adrenaline, serotonin, glutamate, dopamine, gamma-aminobutyric acid (GABA) and endorphins.
- *Deactivators*. These are substances that terminate the activity of the neurotransmitters when they have completed their task. For example, the neurotransmitter ACh is terminated by acetylcholinesterase. Acetylcholinesterase is an enzyme located in the same area as the receptor sites on neuron B. Once ACh has completed its task, it is deactivated by acetylcholinesterase to form acetic acid and choline. The choline is then reabsorbed by the presynaptic neuron to be recycled in the reformation of ACh.

EVENTS AT THE SYNAPSE

The following steps detail the events at the synapse (Fig. 10.10):

1. The action potential travels along neuron A to its axon terminal.
2. Calcium ions (Ca^{2+}) enter the terminal of neuron A.
3. Calcium causes vesicles containing a neurotransmitter to form. These vesicles move towards the membrane of the axon terminal.
4. The vesicles fuse with the membrane of the axon terminal. The vesicles open and release the neurotransmitter into the synaptic cleft.
5. The neurotransmitter diffuses across the synaptic cleft and binds to the receptor site. The binding of the neurotransmitter to the receptor site causes a change in the membrane potential of the dendrite of neuron B, thereby developing a nerve impulse. The neurotransmitter then vacates the receptor and is degraded by enzymes.

Electrical information travels towards the cell body and axon of neuron B. The synapse is crucial in the transfer of signals between neurons. Information from neuron A has been transmitted chemically to neuron B.

Checkpoint

1. List the parts of a synapse.
2. How does the nerve impulse (action potential) of the first neuron stimulate the dendrite of a second neuron?

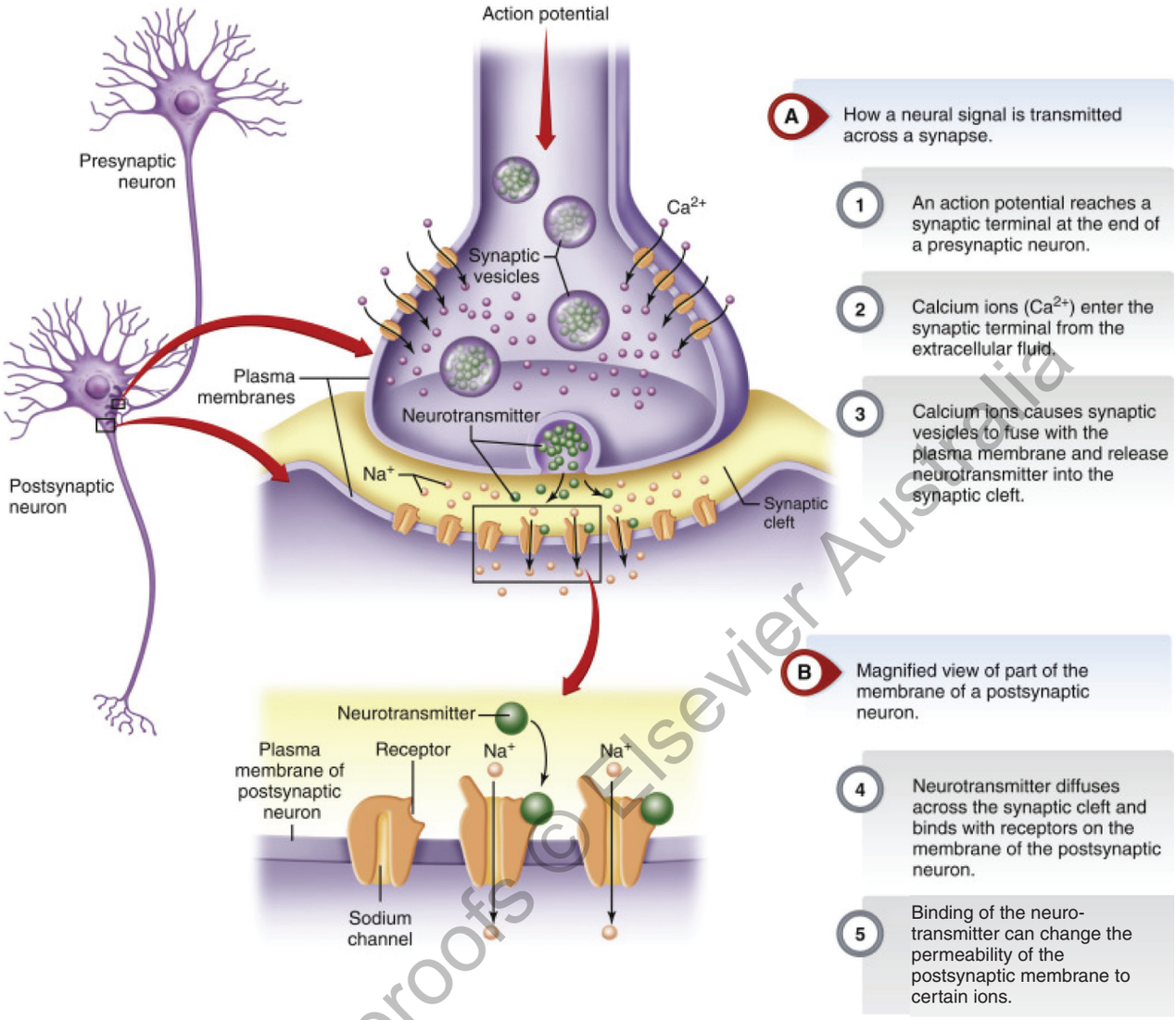

Fig. 10.10 Parts of a Synapse and Synaptic Transmission. The structures and events involved in the transfer of information across a synapse. (EP Solomon 2016. Introduction to Human Anatomy and Physiology, 4th edn. Elsevier, Maryland Heights. Fig. 6-6.)

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Concept Overview

The electrical signal that travels along the neuron is called the *nerve impulse* or *action potential*. The nerve impulse has two main phases: depolarisation and repolarisation. The resting membrane potential and the phases of the nerve impulse are caused by the movement of ions, particularly Na^+ and K^+. The resting membrane potential is due to the outward leak of K^+. Depolarisation is due to the influx of Na^+. Repolarisation is due to the rapid efflux of K^+. Initial depolarisation must reach threshold potential in order for the nerve impulse to develop. The nerve impulse travels along the neuron from the dendrites to the cell body to the end of the axon. Many of the axons are myelinated to increase the speed of the nerve impulse. During saltatory conduction, the nerve impulse jumps from node to node, thereby rapidly moving along the axon. The nerve impulse stimulates the release of neurotransmitters into the synaptic cleft; the transmitter diffuses across the synaptic cleft, binds to the postsynaptic receptor and stimulates the dendrites of the second neuron. The synapse allows for the chemical transmission of information from neuron to neuron.

10.5 THE BRAIN: STRUCTURE AND FUNCTION

The brain is located in the cranial cavity. It is a pinkish-grey, delicate structure with a soft consistency and weighs between 1300 and 1400 grams. The surface of the brain appears bumpy, much like a walnut, to increase surface area.

The blood supply to the brain is unique and is described in Chapter 17. Despite the fact that the brain weighs only 2% of the total body weight, it requires 20% of the body's oxygen supply. The primary source of energy for the brain is glucose. When blood glucose levels get very low (hypoglycaemia), the person experiences mental confusion, dizziness, seizures, loss of consciousness and death. For this reason, many of the body's hormones are concerned with making glucose available to the brain.

The brain is divided into four major areas: the cerebrum, the diencephalon, the brain stem and the cerebellum (Fig. 10.11).

CEREBRUM

The **cerebrum** (seh-REE-brum) is the largest part of the brain. It is divided into the right and left cerebral hemispheres. The cerebral hemispheres are joined together by bands of white matter that form a large fibre tract called the **corpus callosum** (KOHR-puhs kah-LOH-sum). The corpus callosum allows the right and left sides of the brain to communicate with each other. Each cerebral hemisphere has four major lobes: frontal, parietal, temporal and occipital (Fig. 10.12). These four lobes are named for the overlying cranial bones.

ARRANGEMENT OF GREY AND WHITE MATTER

The cerebrum contains both grey and white matter. A thin layer of grey matter, called the *cerebral cortex*, forms the outermost portion of the cerebrum. The cerebral cortex is composed primarily of cell bodies and interneurons and is therefore grey. The grey matter of the cerebral cortex allows us to perform higher mental tasks, such as learning, reasoning, language and memory.

The bulk of the cerebrum is composed of white matter located directly below the cortex. The white matter is composed primarily of myelinated axons that form connections between the parts of the brain and spinal cord. Scattered throughout the white matter are patches of grey matter called *nuclei*.

Point of Interest

Cerebral Lateralisation

Some years ago, a surgeon severed the corpus callosum in the brain of a patient with severe epilepsy. This surgical procedure eliminated all communication between the left and right cerebral hemispheres. From these and other experiments, neuroscientists learned that there is a left brain and a right brain and that these two brains have different abilities. The difference in function between the two cerebral hemispheres is called *cerebral lateralisation*. The left brain is more concerned with language and mathematical abilities; it is the reasoning and analytical side of the brain. The right side of the brain is more concerned with spatial relationships, intuition, art, music and the expression of emotions. Many of us are predominantly left-brain or right-brain persons; however, our lives are enhanced when both sides of our brains are used collaboratively.

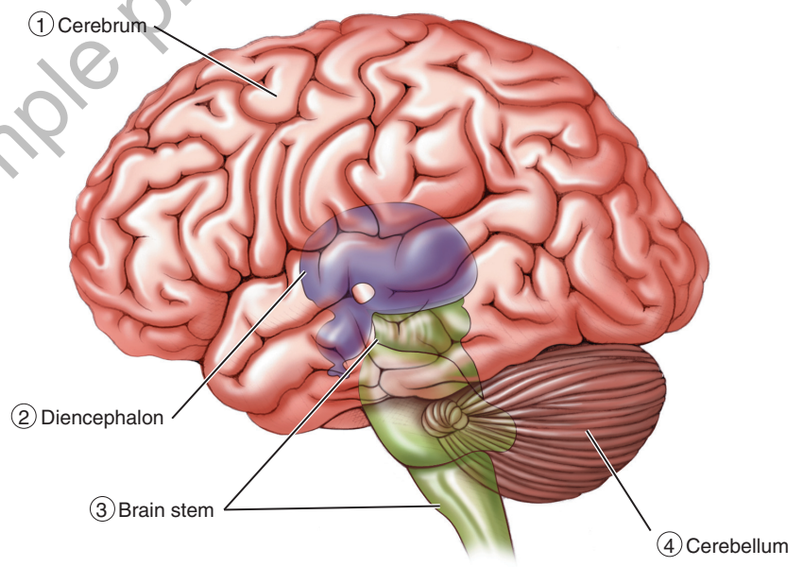

Fig. 10.11 Four Major Areas of the Brain. Cerebrum, diencephalon, brain stem and cerebellum.

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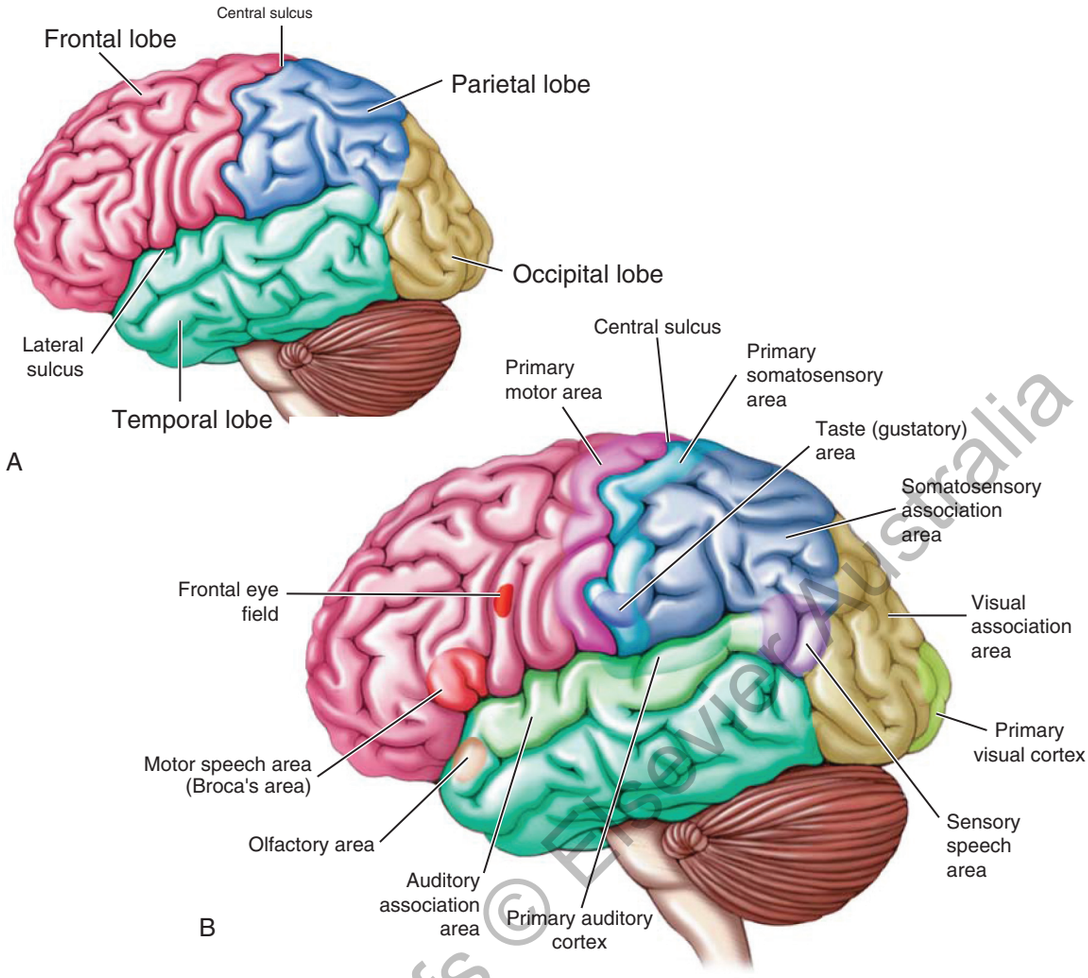

Fig. 10.12 Functional Areas of the Brain. (A) Lobes of the cerebrum. Frontal lobe, parietal lobe, temporal lobe and occipital lobe. **(B)** Functional areas of the cerebrum.

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MARKINGS OF THE CEREBRUM

The bumpy surface of the cerebrum has numerous markings with specific names. The surface of the cerebrum is folded into elevations that resemble speed bumps on a road. The elevations are called **convolutions**, or *gyri* (sing., **gyrus**).

This extensive folding arrangement increases the amount of cerebral cortex, or tissue dedicated to thinking. It is thought that intelligence is related to the amount of cerebral cortex and therefore to the numbers of convolutions or gyri. The greater the numbers of convolutions in the brain, the more intelligent the species. For example, the cerebral cortex of the human brain has many more convolutions than the brain of an elephant (except in the memory part of the brain).

Gyri are separated by grooves called *sulci* (SUL-see) (sing., **sulcus**). A deep sulcus is called a **fissure**. Sulci and fissures separate the cerebrum into lobes. Fig. 10.12 illustrates two of the main sulci and fissures: the central sulcus and the lateral sulcus. (Identify each structure on the diagram as it is described in the text.)

The central sulcus separates the frontal lobe from the parietal lobe. The central sulcus is an important landmark, separating the precentral and postcentral gyri. The precentral gyrus is located in the frontal lobe, directly in front of the central sulcus, and the postcentral gyrus is located in the parietal lobe, directly behind the central sulcus. The lateral sulcus separates the temporal lobe from the frontal and the parietal lobes. The longitudinal fissure separates the left and right cerebral hemispheres (not shown).

Checkpoint

1. What is the major source of energy for the brain?
2. What are the four major divisions of the brain?
3. What is the role of the corpus callosum?
4. In what cerebral lobe is the precentral gyrus? The postcentral gyrus?

LOBES OF THE CEREBRUM

The cerebral lobes are not only structural divisions, but also functional divisions (Table 10.2).

Frontal Lobe

The **frontal lobe** is located in the front of the cranium under the frontal bone (Fig. 10.12). The frontal lobe plays a key role in voluntary motor activity, personality development, emotional and behavioural expression and performance of high-level tasks, such as learning, thinking and making plans; these are sometimes called *executive functions*. The frontal lobe also contains the primary motor area (cortex). Nerve impulses that originate in the primary motor cortex control voluntary muscle movement. When you decide to move your leg, the nerve impulse originates in the precentral gyrus, or primary motor cortex, of the frontal lobe. The axons of these motor neurons form the voluntary motor tracts that descend down the spinal cord.

The function of the precentral gyrus of the frontal lobe is illustrated by a homunculus (hom-UNK-you-luhs), meaning 'little man' (Fig. 10.13). The homunculus represents the amount of brain tissue that corresponds to a function of a particular body part. The homunculus shows two important points: each part of the body is controlled by a specific area of the cerebral cortex of the precentral gyrus; and the complicated nature of certain movements requires large amounts of brain tissue. (Locate the specific points for the toe, foot, leg, trunk, hand and face.)

For example, the movements of the hand are much more delicate and complicated than the movements of the foot. Therefore, the amount of brain tissue devoted to hand and finger movement is much greater than the amount devoted to foot and toe movement. Consequently, the homunculus has huge hands and small feet. Note also the amount of brain tissue required to talk, smile and swallow.

In addition to its role in voluntary motor activity, the frontal lobe plays a key role in motor speech. Motor speech refers to the movements of the mouth and tongue necessary for the formation of words to express your thoughts. The part of the frontal lobe concerned with motor speech is called *Broca's area*. In most people, Broca's area is in the left hemisphere (Fig. 10.12). If Broca's area becomes damaged, as commonly happens with a stroke or brain attack, the person develops a type of aphasia. The person knows what he or she wants to say but cannot say it. Just above Broca's area is an area called the *frontal eye field*. It controls voluntary movements of the eyes and the eyelids. Your ability to scan this paragraph is a function of this area.

Table 10.2 Brain Structure and Function

STRUCTURE	FUNCTIONS
Cerebrum	
Frontal lobe	Motor area, personality, behaviour, emotional expression, intellectual functions, memory storage
Parietal lobe	Somatosensory area (especially from skin and muscle; taste; speech; reading)
Occipital lobe	Vision, vision-related reflexes and functions (reading, judging distances, seeing in three dimensions)
Temporal lobe	Hearing (auditory area), smell (olfactory area), taste, memory storage, part of speech area
Diencephalon	
Thalamus	Relay structure and processing centre for most sensory information going to the cerebrum
Hypothalamus	Integrating system for the autonomic nervous system; regulation of temperature, water balance, sex, thirst, appetite and some emotions (pleasure and fear); regulates the pituitary gland and controls endocrine function
Brain Stem	
Midbrain	Relays information (sensory and motor); associated with visual and auditory reflexes
Pons	Relays information (sensory and motor); plays a role in respiration
Medulla oblongata	Vital function (regulation of heart rate, blood flow, blood pressure, respiratory centres); reflex centre for coughing, sneezing, swallowing and vomiting
Cerebellum	Stabilises and coordinates voluntary muscle activity; helps in the maintenance of balance and muscle tone
Other Structures	
Limbic system	Experience of emotion and behaviour (emotional brain)
Reticular formation	Alerts the cerebrum of incoming sensory signals; regulates muscle tone in the resting body; includes the reticular activating system (RAS) and regulates the sleep–wake cycle
Basal nuclei	Smooths out and coordinates skeletal muscle activity

? Checkpoint

1. What are the functions of the frontal lobe? Of Broca's area? Of the frontal eye fields?
2. What information is conveyed by a homunculus?

Parietal Lobe

The **parietal lobe** (pah-RYE-i-tal lohb) is located posterior to the central sulcus (Fig. 10.12). The parietal lobe, particularly the postcentral gyrus, is primarily concerned with receiving general sensory information

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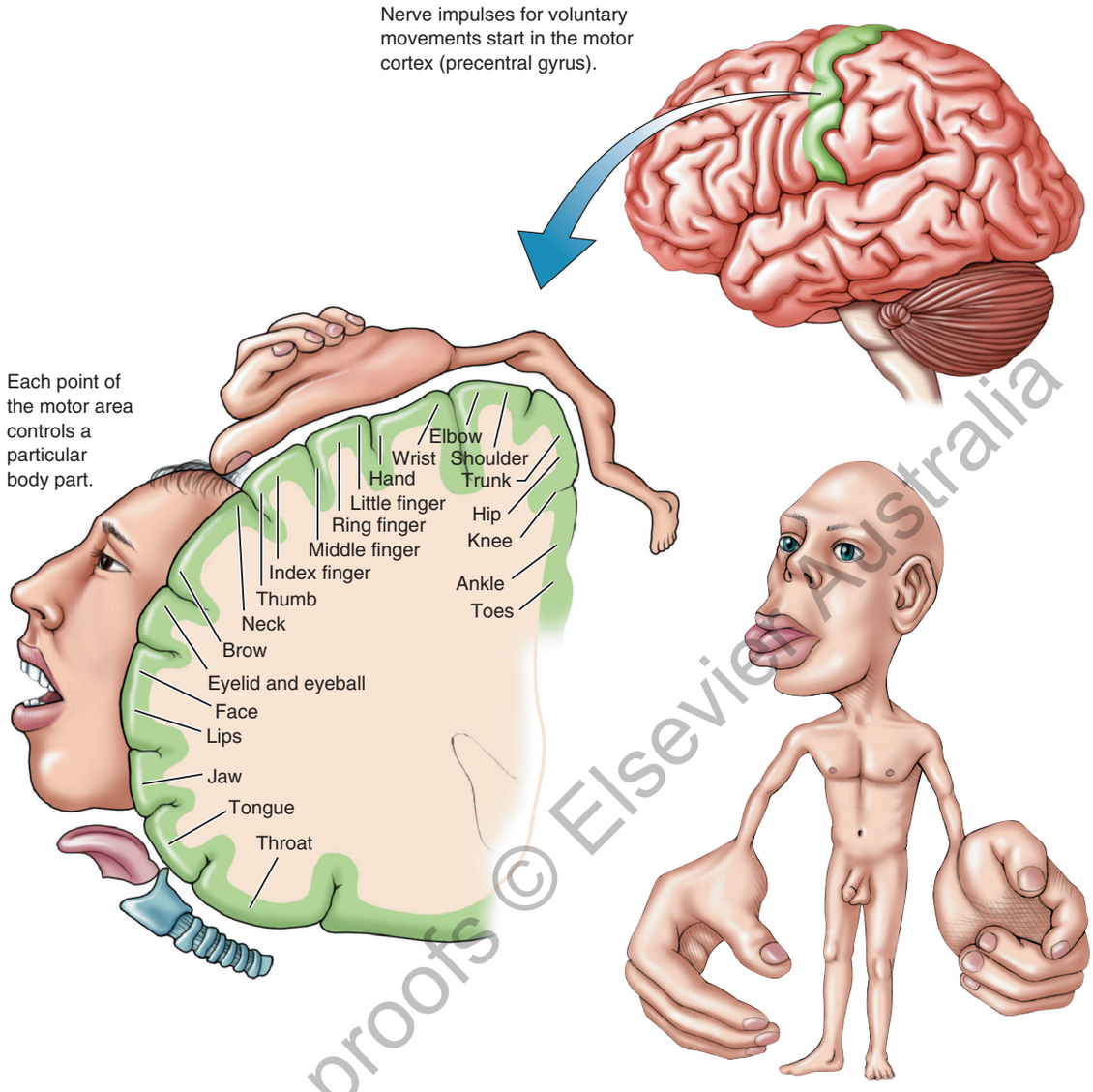

Fig. 10.13 Motor Area of the Frontal Lobe (Precentral Gyrus), Illustrated with a Homunculus.

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from the body. Since it receives sensations from the body, the parietal lobe is called the *primary somatosensory area.* This area receives information primarily from the skin and muscles and allows you to experience the sensations of temperature, pain, light touch and proprioception (a sense of where your body is). The parietal lobe is also concerned with reading, speech and taste. Like the motor homunculus in the precentral gyrus, a sensory homunculus can be drawn along the postcentral gyrus (not shown). The precentral gyrus is located in the frontal lobe and is the primary motor area. The postcentral gyrus is located in the parietal lobe and is the primary somatosensory area.

Temporal Lobe

The **temporal lobe** (TEM-poh-ral lohb) is located inferior to the lateral fissure in an area just above the ear (Fig. 10.12). The temporal lobe contains an area called the *primary auditory cortex.* It receives sensory information from the ears and allows you to hear. Damage to the temporal lobe causes cortical deafness. The temporal lobe also receives sensory information from the nose; this area is called the *olfactory area*, the area that senses smell. Sensory information from the taste buds in the tongue is interpreted in both the temporal and the parietal lobes. A broad region called *Wernicke's area* (not shown) is located in the parietal and temporal lobes; it is concerned with the translation of thoughts into words. Damage to this area, as occurs with chronic alcohol abuse, can result in severe deficits in language comprehension.

Occipital Lobe

The **occipital lobe** (ok-SIP-it-al lohb) is located in the posterior part of the cerebrum, underlying the

occipital bone (Fig. 10.12). The occipital lobe contains the visual cortex. Sensory fibres from the eye send information to the primary visual cortex of the occipital lobe, where it is interpreted as sight. The occipital lobe is also concerned with many visual reflexes and vision-related functions, such as reading (through the visual association area). Damage to the primary visual cortex of the occipital lobe causes cortical blindness.

FUNCTIONS INVOLVING MULTIPLE LOBES

Speech Area

Although specific functions can be attributed to each cerebral lobe, most functions depend on more than one area of the brain. The speech area, for example, is located in an area that includes the temporal, parietal and occipital lobes. In most people, the speech area is located in the left hemisphere. The speech area allows you to understand words, whether written or spoken. When you have gathered your thoughts, Broca's area in the frontal lobe directs the muscles of the larynx, tongue, cheeks and lips to speak.

Point of Interest

Contralateral Neglect Syndrome

A person with a lesion in the parietal lobe may become unaware of the opposite side of his body. For example, he may not recognise his left leg as his own. When shaving, he may shave only one side of his face. When dressing, he may dress only one side of his body. When eating, he may eat only foods on one side of his plate. This neurological condition is called *contralateral neglect syndrome*.

Other functions require input from more than one brain structure. The ability to read, for example, requires interpretation of the visual information by the occipital lobe. It also requires understanding of the words and the coordination of the eyes as they scan the page. A vast amount of brain tissue beyond the occipital lobe is involved in vision and vision-related functions such as reading.

Checkpoint

1. Identify the cerebral lobes concerned with these functions: vision, hearing, taste, smell and speech.
2. Identify one consequence of damage to Wernicke's area.

ASSOCIATION AREAS

Large areas of the cerebral cortex are called **association areas** (Fig. 10.12). These areas are concerned primarily with analysing, interpreting and integrating information. For example, a small area of the temporal lobe, called the *primary auditory cortex*, receives sensory information from the ear. The surrounding area, called the *auditory association area*, uses a large store of knowledge and experience to identify and give meaning to the sound. In other words, the auditory cortex hears the noise and the auditory association area interprets the noise. The brain contains receiving and association areas for other sensations as well (e.g. visual association area, somatosensory association area).

GREY MATTER WITHIN WHITE MATTER

Scattered throughout the cerebral white matter are patches of grey matter called *basal nuclei* (sometimes called *basal ganglia*). The basal nuclei help regulate body movement and facial expression. The neurotransmitter dopamine is largely responsible for the activity of the basal nuclei.

A deficiency of dopamine within the basal nuclei is called *Parkinson's disease*. It is a movement disorder or *dyskinesia* (dis-kin-EE-see-ah). Due to the characteristic shaking (tremors), Parkinson's disease is sometimes called *shaking palsy*. Dopamine-producing drugs are usually prescribed to treat this condition.

DIENCEPHALON

The *diencephalon* (dye-en-SEF-ah-lon) is the second main area of the brain. It is located beneath the cerebrum and above the brain stem. The diencephalon includes the thalamus and the hypothalamus (Fig. 10.14).

The **thalamus** (THAL-ah-muhs) serves as a relay station for most of the sensory fibres travelling from the lower brain and spinal cord region to the sensory areas of the cerebrum. The thalamus sorts out the sensory information, gives us a hint of the sensation we are to experience and then directs the information to the specific cerebral areas for more precise interpretation. For example, pain fibres coming from the body to the brain pass through the thalamus. At the level of the thalamus, we become aware of pain, but we are not yet aware of the type of pain or the exact location of the pain. Fibres that transmit pain information from the thalamus to the cerebral cortex provide us with that additional information.

The **hypothalamus** (hye-poh-THAL-ah-muhs) is the second structure in the diencephalon. It is situated directly below the thalamus and helps regulate many body processes, including body temperature (thermostat), water balance and metabolism. Since the hypothalamus helps regulate the function of the autonomic (involuntary) nerves, it exerts an effect on heart rate, blood pressure and respiration.

Located under the hypothalamus is the pituitary gland. The pituitary gland directly or indirectly affects almost every hormone in the body. As the hypothalamus controls pituitary function, the widespread effects of the hypothalamus are obvious (see Chapter 14 for a description of the hypothalamus and endocrine function).

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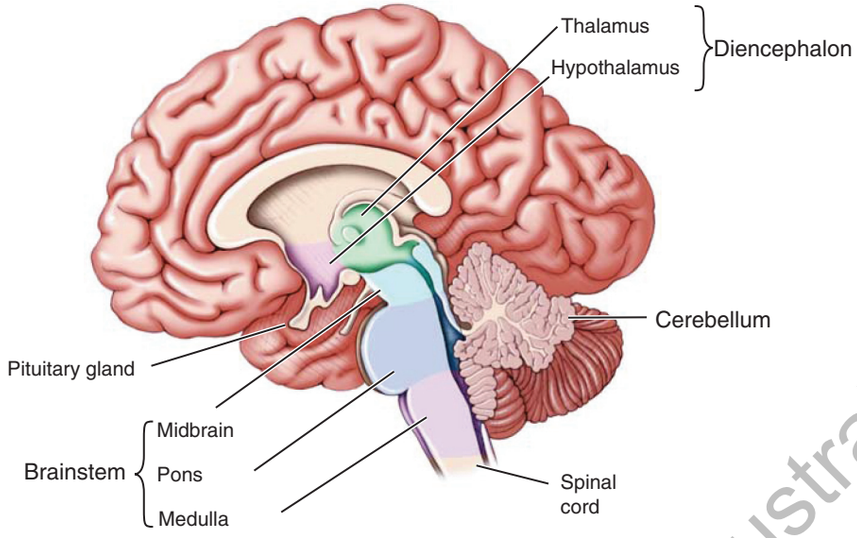

Fig. 10.14 Diencephalon, Brain Stem and Cerebellum. The diencephalon consists of the thalamus and hypothalamus. The brainstem is composed of the midbrain, pons and medulla. Note the relationship between the hypothalamus and pituitary gland.

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Checkpoint

1. What roles do the visual and auditory association areas play?
2. What is the function of the basal nuclei?
3. What is the relationship of the hypothalamus to the pituitary gland?
4. What functions are influenced by the hypothalamus?

BRAIN STEM

The **brain stem** connects the spinal cord with higher brain structures. It is composed of the midbrain, pons and medulla oblongata (Fig. 10.14). The white matter of the brain stem includes tracts that relay both sensory and motor information to and from the cerebrum. Scattered throughout the white matter of the brain stem are patches of grey matter called *nuclei*. These nuclei exert profound effects on functions such as blood pressure and respiration.

MIDBRAIN

The midbrain extends from the lower diencephalon to the pons. Like the rest of the brain-stem structures, the midbrain relays sensory and motor information. The midbrain also contains nuclei that function as reflex centres for vision and hearing.

PONS

The pons (bridge) extends from the midbrain to the medulla oblongata. It is composed primarily of tracts that act as a bridge for information travelling to and from several brain structures. The pons also plays an important role in the regulation of breathing rate and rhythm and is often referred to as the *pneumotaxic centre*.

MEDULLA OBLONGATA

The **medulla oblongata** (meh-DUL-ah oh-blohn-GAHT-ah) connects the spinal cord with the pons. The medulla acts as a relay for sensory and motor information. Several important nuclei within the medulla control the vital functions: heart rate, blood pressure and respiration. Because of its importance with regard to these life-sustaining functions, the medulla oblongata is called the *vital centre*.

The medulla oblongata is sensitive to certain drugs, especially opioids such as morphine. An overdose of an opioid causes depression of the medulla oblongata and death because the person stops breathing. This danger is the reason for assessing respiratory rate before giving a patient an opioid.

Point of Interest

Biological Tranquillisers

The brain produces natural morphine-like substances called *endorphins* (endogenous morphine) and *enkephalins* (meaning 'in the head'). Like morphine, these substances bind to opiate receptors in the CNS, moderating pain, relieving anxiety and producing a sense of well-being. The 'high' experienced by joggers may be caused by endorphins and enkephalins.

Vomiting Centre

The medulla oblongata contains the vomiting centre, or emetic centre (emesis refers to vomiting). The vomiting centre can be activated directly or indirectly. Direct activation includes stimuli from the cerebral cortex (fear), stimuli from sensory organs (distressing sights, bad odours, pain) and signals from the equilibrium apparatus of the inner ear (spinning). Indirect

stimulation of the vomiting centre comes from the chemoreceptor trigger zone (CTZ) located in the floor of the fourth ventricle. The CTZ can be stimulated by emetogenic compounds, such as anti-cancer drugs and opioids. Signals from the digestive tract, especially the stomach, travel via the vagus nerve to the CTZ. The CTZ, in turn, activates the vomiting centre. Antiemetic agents can work on both the CTZ and the medullary vomiting centre to relieve nausea and vomiting. The pharmacological management of vomiting is a common clinical problem. Another interesting point is that nausea, which often precedes vomiting, is derived from the Greek word for 'ship', as in seasickness.

Checkpoint

1. List the three parts of the brain stem.
2. Why is the medulla oblongata called the vital centre?
3. Differentiate between the vomiting centre and the CTZ.

CEREBELLUM

The **cerebellum** (sair-eh-BELL-um), the fourth major area, is the structure that protrudes from under the occipital lobe (Fig. 10. 14). The interior of the cerebellum is composed largely of white tracts. Notice that the appearance of the white tracts within the cerebellum look like a tree and this is therefore called the *arbor vitae* or literally the 'tree of life'. The cerebellum is connected to the brain stem by three pairs of *cerebellar peduncles* (sair-eh-BELL-ahr peh-DUN-kuls); these connections allow the cerebellum to receive, integrate and deliver information to many parts of the brain and spinal cord. The cerebellum is concerned with the coordination of voluntary muscle activity and maintaining equilibrium and posture. Damage to the cerebellum produces jerky muscle movements, staggering gait and difficulty maintaining balance. The person with cerebellar dysfunction may appear intoxicated. To help diagnose cerebellar dysfunction, the doctor may ask the person to touch the tip of his or her nose with a finger. This is because the cerebellum normally coordinates skeletal muscle activity. In attempting to touch the nose, a patient with cerebellar dysfunction may overshoot, first to one side and then to the other.

The cerebellum also plays an important role in the evaluation of sensory input. For example, the cerebellum allows a person to evaluate the texture of different fabrics without seeing the fabric. It also times events, thereby allowing the person to predict where a moving object will be in the next few seconds. For example, a basketball player has a keen sense of where the ball is and should be in the next dribble or two. In addition, most of us can rhythmically drum our fingers on a desk—a task that is impaired in someone with cerebellar dysfunction.

Point of Interest

Brain Scaffolding and Tumours

At several points in the brain, the dura mater forms rigid membranes that separate and support parts of the brain. One such membrane is the tentorium cerebelli; it forms a tent-like membrane over the cerebellum, separating it from the upper cerebral structures. The tentorium also functions as a common landmark in the brain. Brain tumours are classified according to their locations; those that occur in structures located above the tentorium are called *supratentorial brain tumours* and those occurring below the tentorium are called *infratentorial brain tumours*. An increase in intracranial pressure can force the brain downwards past the tentorium, causing life-threatening symptoms. The displacement is called *tentorial herniation*.

Checkpoint

1. Locate and list two functions of the cerebellum.
2. Why is a staggering gait characteristic of cerebellar dysfunction?

STRUCTURES ACROSS DIVISIONS OF THE BRAIN

Three important structures are not confined to any of the four divisions of the brain because they overlap several areas. These structures are the limbic system, the reticular system and the memory areas.

THE LIMBIC SYSTEM

Parts of the cerebrum and the diencephalon form a wishbone-shaped group of structures called the **limbic system** (LIM-bik sis-tem). The limbic system functions in emotional states and behaviour. For example, when the limbic system is stimulated by electrodes, states of extreme pleasure or rage can be induced. Due to these responses, the limbic system is called the *emotional brain*.

RETICULAR FORMATION

Extending through the entire brain stem and diencephalon, with numerous connections to the cerebral cortex, is a special mass of grey matter called the **reticular formation**.

The reticular formation has both a sensory and a motor function. Its primary sensory function is to alert the cerebral cortex of incoming sensory information. Its primary motor function is to regulate muscle tone, the mild state of muscle contraction while the body is at rest.

Other nuclei within the reticular formation include the gaze centres (allow the eyes to track an object) and special groups of cells that rhythmically send signals to the muscles that control breathing and swallowing. The reticular formation is also concerned with habituation, the process whereby the brain learns to ignore repetitive background information. For example, you

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may be unaware of background noise such as people talking and outside traffic, but respond immediately when your phone rings. Similarly, while driving a car, you ignore much of the background visual information, but are aware of traffic signals, nearby cars and any oncoming vehicles.

Reticular Activating System (RAS)

A portion of the reticular formation, the reticular activating system (RAS), is concerned with the sleep–wake cycle, or wakefulness, sleep and coma. Signals passing up to the cerebral cortex from the RAS stimulate us, keeping us awake and tuned in. Diminished activation of the RAS produces sleep, a state from which one can be aroused. In the sixth century, it was believed that sleep was caused by a temporary retreat of blood from the brain. Death was attributed to the permanent retreat of blood from the brain. We still do not know the cause of sleep today, but what we do know is that neurotransmitters are replenished during sleep. We also know that most Australians do not get enough sleep (most adults require 7 to 9 hours of sleep), and that sleep deprivation is linked to numerous health problems, such as obesity, diabetes mellitus and hypertension.

Coma is a hyporesponsive state with several stages, ranging from light to deep coma. In the lightest stages of coma, some reflexes are intact; the patient may respond to light, sound, touch and painful stimuli. As the coma deepens, however, these reflexes are gradually lost and the patient eventually becomes unresponsive to all stimuli. Many clinical conditions affect level of consciousness (LOC) or awareness. Clinically, it is important to be able to assess a patient's LOC.

Checkpoint

1. Locate the limbic system and explain why it is called the emotional brain.
2. State a major role of the reticular activating system.
3. List two ways that you would evaluate LOC.

Stages of Sleep

The two types of sleep are non-rapid eye movement (NREM) sleep and rapid eye movement (REM) sleep. The four stages of NREM sleep progress from light to deep. In a typical 8-hour sleep period, a person regularly cycles through the various stages of sleep, descending from light to deep sleep and then ascending from deeper sleep to lighter sleep.

REM sleep is characterised by fluctuating blood pressure, respiratory rate and rhythm and pulse rate. The most obvious characteristic of REM sleep is rapid eye movements, for which the sleep segment is named. REM sleep totals 90 to 120 minutes per night; most dreaming occurs during REM sleep. For unknown reasons, REM sleep deprivation is associated with mental and physical distress. Most sedatives and CNS depressants adversely affect REM sleep, perhaps accounting for that 'hangover' feeling that often follows their use.

Point of Interest

Chemotherapy-Induced Cognitive Impairments

Many drugs exert profound effects on the brain. There is the euphoria of opioids, the hallucinogenic effects of LSD, the 'buzz' of methamphetamines and the sedation of antihistamines. For many years, breast cancer survivors have complained of the lingering effects of their cancer chemotherapy. Many noted difficulty with memory, attention span, retrieving words, multi-tasking and clarity of thought. For example, one woman filled the water glasses with gravy at a festive dinner. They complain of 'living in a fog'—hence, the term *chemo fog* or *chemobrain*. Chemo fog is real and lingers for many months, even years, after the chemo has ended. Today it has a new, respectable name: *post-chemotherapy cognitive impairment*, or *post-chemotherapy cognitive dysfunction*.

MEMORY AREAS

Memory is the ability to recall thoughts and images. Many areas of the brain are concerned with memory. There are three categories of memory: immediate memory, short-term memory and long-term memory. Immediate memory lasts for a few seconds. An example of your immediate memory is your ability to remember the words in the first part of the sentence so that you can get the thought of the entire sentence. Short-term memory lasts for a short period (seconds to a few hours). It allows you to recall bits of information, such as the price of an item or a phone number that you searched for. For example, cramming for exams is considered short-term memory. Short-term memorisation is followed by 5-second retention and often followed by memory blank. Long-term memory lasts much longer—years, decades or a lifetime. If you continuously use the new address or phone number, you will enter that information into your long-term memory. The same effect is achieved when you study over a longer period. Another interesting point: although memory is important, forgetting is also important. Imagine all the trivial information that you take in every second. Think of the many stones, trees, birds, street signs and other things that you encounter day-to-day. People who have difficulty in forgetting trivia have a great deal of difficulty in comprehension and in remembering things that need to be remembered.

Checkpoint

1. What is REM sleep?
2. List the three categories of memory. Explain why cramming for an exam is an ineffectual learning process.

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Point of Interest

Trephination

Trephination refers to the drilling of holes into the skull for the purpose of reducing intracranial pressure. Today, it is performed in the operating room under sterile conditions; the surgically drilled holes are called *burr holes*. People in ancient times also performed trephination procedures. The patient sat on a log while the priest chipped a hole in the skull using a sharp stone. It was thought that trephination could relieve headaches and release the devils of madness.

10.6 PROTECTION OF THE CENTRAL NERVOUS SYSTEM

The tissue of the CNS (brain and spinal cord) is very delicate. Injury to CNS neuronal tissue cannot be repaired. Thus, the CNS has an elaborate protective system that consists of four structures: bone, meninges, cerebrospinal fluid and the blood–brain barrier.

BONE: THE FIRST LAYER OF PROTECTION

The CNS is protected by bone. The brain is encased in the cranium and the spinal cord is encased in the vertebral column.

MENINGES: THE SECOND LAYER OF PROTECTION

Three layers of connective tissue surround the brain and spinal cord (Fig. 10.15). These tissues are called the **meninges** (meh-NIN-jeez) (sing., *meninx*). The outermost layer is a thick, tough, connective tissue called the *dura mater*, literally meaning 'hard mother'. Inside the skull, the dural membrane splits to form the dural sinuses. These sinuses are filled with blood. Beneath the dura mater is a small space called the *subdural space*. The middle meningeal layer is the arachnoid mater (meaning 'spider-like'), because the membrane looks like a spider's web.

The pia mater is the innermost layer and literally means 'soft or gentle mother'. The pia mater is a very thin membrane that contains many blood vessels and lies delicately over the brain and spinal cord. These blood vessels supply the brain with much of its blood. Between the arachnoid layer and the pia mater is a space called the **subarachnoid space**. A fluid called the **cerebrospinal fluid (CSF)** circulates within this space and forms a cushion around the brain and spinal cord. If the head is jarred suddenly, the brain first bumps into this soft cushion of fluid. Specialised projections of the arachnoid membrane, called the *arachnoid villi* (sing., villus), protrude up into the blood-filled dural sinuses and are involved in the drainage of the CSF (described in the next section).

The ordering of the meninges may be remembered using the acronym **PAD** – **P**ia mater, **A**rachnoid mater, **D**ura mater (noting that the brain is closer to pia, the softer mother).

The meninges can become inflamed or infected, causing meningitis. Meningitis is serious because the infection can spread to the brain, sometimes causing serious, irreversible brain damage. The bacterial or viral organism causing the meningitis can often be found in a sample of CSF obtained by lumbar puncture.

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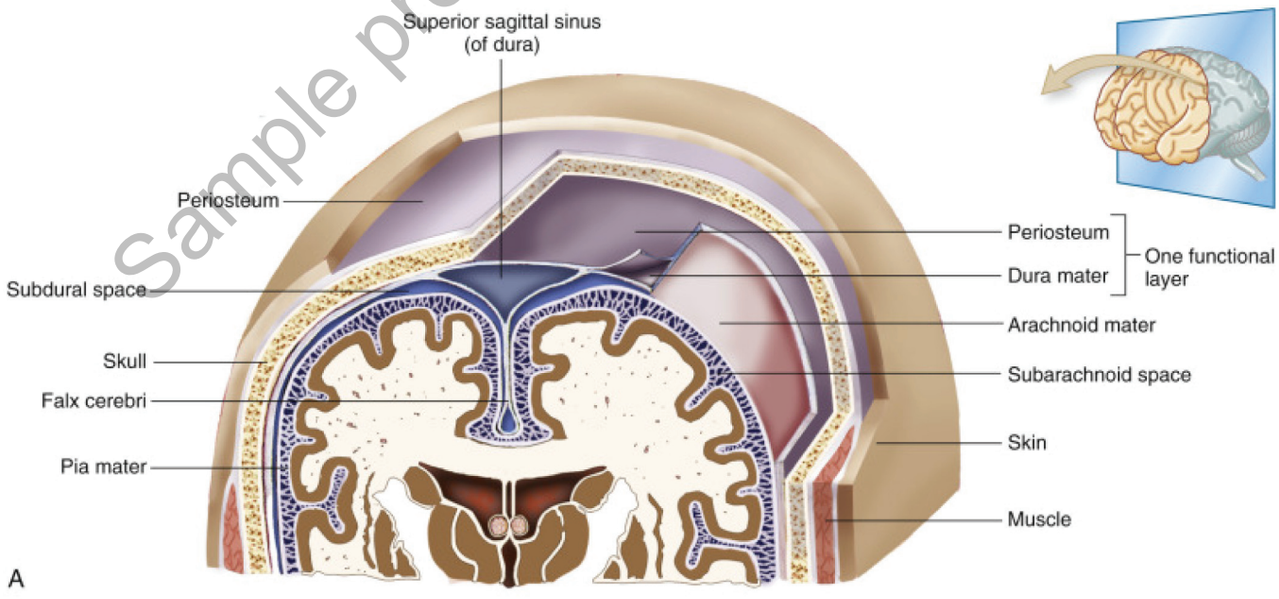

Fig. 10.15 Three Layers of Meninges. The dura mater, arachnoid mater and pia mater. Note the subarachnoid space, the subdural space and dural sinus. (G Koutoukidis, K Stainton, J Hughson 2017. Tabbner's Nursing Care, 7th edn. Elsevier, Chatswood. Fig. 35.4.)

CEREBROSPINAL FLUID: THE THIRD LAYER OF PROTECTION

The CSF forms a third protective layer of the CNS. CSF is formed from the blood within the brain. It is a clear, colourless fluid similar in composition to plasma. The CSF is composed of water, glucose, protein and several ions, especially Na^+ and Cl^-. An adult circulates about 130 mL of CSF; 500 mL is formed every 24 hours, so CSF is replaced every 8 hours. In addition to its protective function, CSF also delivers nutrients to the CNS and removes waste.

CSF is formed within the ventricles of the brain by a structure called the **choroid plexus** (Fig. 10.16). The four ventricles are two lateral ventricles and a third and fourth ventricle. The choroid plexus, a grape-like collection of blood vessels and ependymal cells (Table 10.1), is suspended from the roof of each ventricle. Water and dissolved substances are transported from the blood across the walls of the choroid plexus into the ventricles (Fig. 10.16).

The CSF is not static but flows. As CSF leaves the ventricles it follows two paths. Some of the CSF flows through a hole in the centre of the spinal cord called the *central canal*. The central canal eventually drains into the subarachnoid space at the base of the spinal cord. The rest of the CSF flows from the fourth ventricle laterally through tiny holes, or foramina, into the subarachnoid space that encircles the brain.

The CSF will eventually leave the subarachnoid space and flow into the arachnoid villi; water and waste diffuse from CSF in the arachnoid villi into the blood of the dural sinuses. Blood then flows from the dural sinuses into the cerebral veins and back to the heart.

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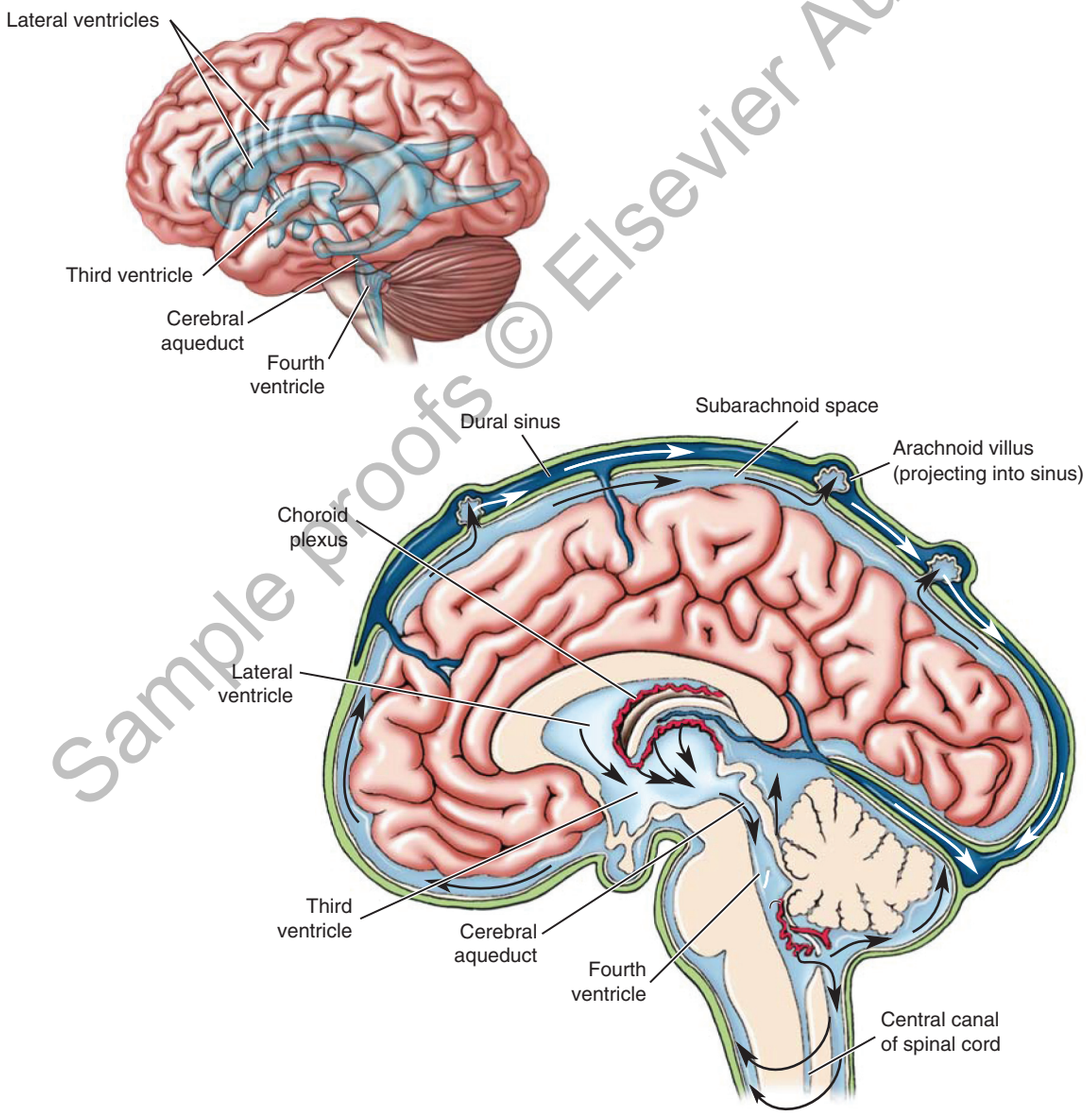

Fig. 10.16 Cerebrospinal Fluid. Formation from the choroid plexus and circulation through the ventricles, within the subarachnoid space and in the central canal. Drainage through the arachnoid villi and dural sinuses.

Remember that the CSF is formed across the walls of the choroid plexus within the ventricles, circulates throughout the subarachnoid space around the brain and spinal cord and then drains into the dural sinuses. The rate at which CSF is formed must equal the rate at which it is drained. If excess CSF is formed or drainage is impaired, CSF will accumulate in the ventricles of the brain, increasing the pressure within the skull. If the flow of CSF occurs before the sutures in the skull fuse, a child may develop hydrocephalus, increased intracranial pressure and brain damage. Fortunately, shunting procedures restore the flow of CSF by surgically creating a detour around the blocked pathway.

Point of Interest

The Choroid Plexus Worm

In the 1300s, an anatomist claimed that mental function was controlled by a red worm. The worm referred to the fleshy choroid plexus of the ventricles of the brain. The plexi allegedly controlled brain functions by wiggling back and forth and modifying the flow of cerebrospinal fluid (CSF), which was supposed to contain the animal spirit. Several functions of the choroid plexus have since been identified; mental function is the result of neuronal activity, and not the flow of animal spirit, while the choroid plexus secretes CSF but does not move. There is, however, a little red worm, the choroid plexus, and it is located in the ventricles of the brain where it secretes CSF.

BLOOD–BRAIN BARRIER: THE FOURTH LAYER OF PROTECTION

The blood–brain barrier is an arrangement of cells, particularly the glial astrocytes and the selectively permeable capillary cells; they act as a barrier to the movement of potentially harmful chemicals into the CNS. The astrocytes and the capillary cells select the substances allowed to enter the CNS from the blood. For example, oxygen, glucose and certain ions readily cross the membrane. However, if a potentially harmful substance is present in the blood, the cells of the blood–brain barrier prevent that substance from entering the brain and the spinal cord.

Although the blood–brain barrier is successful in screening many harmful substances, not all toxic substances are blocked. Alcohol, for example, crosses the blood–brain barrier and affects brain tissue.

The blood–brain barrier may present a problem in the pharmacological treatment of infections within the CNS. Most antibiotics, for example, cannot cross the blood–brain barrier and therefore cannot reach the site of infection. Given this situation, treatment of infections in the CNS requires consideration. The two options are to select an antibiotic that does cross the blood–brain barrier or inject the antibiotic directly into the subarachnoid space; this mode of drug delivery is called an *intrathecal injection*.

Checkpoint

1. Trace the formation, flow and drainage of CSF.
2. What is the consequence of obstructed drainage of CSF?
3. What is the blood–brain barrier?
4. What effect might the blood–brain barrier have on drug distribution?

Concept Overview

The brain makes us humans—that is, thinking, sensing, doing, caring, feeling, remembering individuals. It also coordinates the various organ systems of the body efficiently, with fine precision. The brain is divided into four regions: the cerebrum, diencephalon, brain stem and cerebellum. The cerebrum is the largest part of the brain and has four lobes: frontal, parietal, temporal and occipital. The diencephalon is composed of the thalamus and the hypothalamus. The brain stem is composed of the midbrain, pons and medulla oblongata. The medulla oblongata is considered the vital structure in that it affects basic functions such as respiration, cardiac function and blood vessel tone. Three other areas are the reticular formation, which keeps us awake; the limbic system (emotional brain); and the memory areas. Due to the crucial role played by the CNS, it is afforded excellent protection—that is, bone, three layers of meninges, a soft cushion of CSF fluid and a blood–brain barrier.

Spotlight on Ageing

1. Beginning at the age of 30, the number of neurons decreases. The number lost, however, is only a small percentage of the total number of brain cells and does not cause mental impairment. Although a decrease in short-term memory may cause some forgetfulness, most memory, alertness, intellectual functioning and creativity remain intact. Severe alteration of mental functioning is generally caused by age-related diseases such as arteriosclerosis.
2. Impulse conduction speed decreases along an axon, amounts of neurotransmitters are reduced and the number of receptor sites decreases at the synapses. These changes result in progressive slowing of responses and reflexes.

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Medical Terminology and Disorders — Disorders of the Brain

MEDICAL TERM	WORD PARTS	WORD PART MEANING OR DERIVATION	DESCRIPTION
Terms			
Meninges		From a Latin word meaning 'membrane'	The meninges are the three membranes that form the outer lining of the brain and spinal cord. The Arabs referred to these membranes as *mater* (mother) because they believed these membranes were the 'mother' of all membranes
Neurology	neur/o- -logy	Nerve Study of	Neurology is the study of the structure, function and organic disorders of the nervous system
Polarise		From a French word meaning a 'division within a group'	Refers to a separation of electrical charge. A polarised nerve cell has a negative charge on the inside of the cell membrane and a positive charge on the outside of the cell membrane. The electric charge of a *depolarised* (*de* = away from) cell becomes positive. A *repolarised* (*re* = again) cell has returned to an internal negative charge
Synapse	syn- -apse	Together From a Greek word, *haptein,* meaning 'to clasp'	A synapse is a junction or meeting place for two neurons. The axon of one neuron interacts chemically at a synapse with the dendrite of a second neuron
Disorders			
Cephalgia	cephal/o- -algia	Head Pain	Pain in the head or headache. An example is the *migraine headache*, a severe, recurring headache that usually affects only one side of the head. (*Migraine* comes from the Latin *hemicranium*, meaning 'one side of the head'). A simple tension headache may develop when a person is anxious or tense. Headaches may also develop secondarily in response to increased intracranial pressure (e.g. brain tumour), irritation of the meninges, or spasm of the cerebral blood vessels. *Cluster headaches* occur in cyclic patterns and are called 'alarm clock headaches' because they often awaken the person with intense and sharp pain in and around one eye
Cerebrovascular Accident (CVA)			A cerebrovascular accident (CVA), also called a *stroke* or *brain attack*, is caused by a sudden lack of blood, causing oxygen deprivation and brain damage. Depending on the location and severity of the brain damage, a CVA can result in loss of sensory and motor function and speech impairment. The patient often experiences *hemiparalysis* (hemi- = half) and *hemiparesis*. In addition to loss of motor function, the patient experiences various types of *aphasia* (a- = without; phas/o = speech), *an impairment of language*. Before suffering a stroke, many persons will have experienced a *transient ischaemic attack* (TIA), or *mini stroke*. During a TIA, blood flow to the brain is temporarily stopped or diminished
Dementia	de- -ment/o- -ia	Without Mind Condition of	Originally from the Latin meaning 'madness'. Dementia is not a single disease, but a group of symptoms affecting intellectual and social abilities to the extent that daily living is impaired. There is a serious loss of cognitive ability, with impairment of language, problem solving, memory, attention and judgement. Behaviour may be disorganised, restless and inappropriate. *Static dementia* is commonly caused by traumatic brain injury. *Progressive dementia* refers to a long-term decline and is caused by chronic conditions such as *Alzheimer's disease*, *multiple sclerosis* and small or mini strokes (*vascular dementia*)

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Medical Terminology and Disorders Disorders of the Brain—cont'd

MEDICAL TERM	WORD PARTS	WORD PART MEANING OR DERIVATION	DESCRIPTION
Dyskinesias	dys-	Difficulty	Any medical disorder that is characterised by diminished voluntary muscle control (a movement disorder). This broad term includes *Parkinson's disease*, *Tourette's syndrome* (muscle tics, verbal outbursts, sometimes profanity), *chorea* ('dance-like' muscle contractions that begin in one part of the body [toe] and work their way to another part [leg]), *athetosis* (graceful but purposeless movements primarily of the extremities) and *asterixis* ('flapping tremor' of the wrists). The term dyskinesia also includes many *dystonias* (impaired muscle tone), sustained muscle contractions that twist or contort the body. Some types of dyskinesias are localised, as in *torticollis* (lateral flexion of the neck caused by muscle spasm), whereas others are generalised, as in epileptic seizures. *Tardive dyskinesias* (TDs), often a result of antipsychotic drug therapy and dopaminergic antagonists, are characterised by involuntary movement of the lips (lip smacking), tongue (tongue rolling, protrusions), face, trunk and extremities. Drug-induced TDs are usually irreversible
	-kinesi/o-	Movement	
	-ia	Condition of	
Encephalopathy	en-	Within	A broad term that refers to disease, damage, or dysfunction of the brain. There are more than 150 types. The term encephalopathy is often described by its cause. *Anoxic encephalopathy* is due to a lack of oxygen, whereas *hepatic encephalopathy* is a response to liver disease. Chronic and excessive ingestion of alcohol causes irreversible injury to the nervous system. The result is mental deterioration, loss of memory, inability to concentrate, irritability and uncoordinated movement. *Wernicke–Korsakoff syndrome* is an alcohol-related type of encephalopathy
	-cephal/o-	Head	
	-path/o-	Disease	
	-y	Condition or process	
Epilepsy	epi-	Upon	Historically referred to as the 'sacred disease' by the ancients because they believed that epilepsy was a punishment for offending the gods. Epilepsy is a group of neurological disorders that all present with spontaneous seizure activity. Neurons in the brain fire suddenly, unpredictably and repetitively, creating 'electrical storms' in the brain. Although most cases of epilepsy are idiopathic (arising spontaneously or unknown) in origin, many underlying conditions cause seizure activity: brain tumours, toxins, trauma, fever (*febrile seizures*) and emotional stress. Epileptic seizures are classified as primarily generalised seizures (a widespread electrical storm including both sides of the brain) and partial seizures (more limited brain involvement and localised responses). There are many types of seizures, two of which are *tonic-clonic seizures* (grand mal) and *absence seizures* (petit mal). The tonic phase of a grand mal seizure occurs when the motor areas fire repetitively, causing muscle stiffening and loss of consciousness. The clonic phase is characterised by jerking activity. *Status epilepticus*, a medical emergency, refers to the failure of the seizures to resolve or to the rapid succession of seizure activity. Absence seizures occur when sensory areas are affected, causing a brief period (5–15 seconds) of altered consciousness. They are not accompanied by generalised stiffening or prolonged unconsciousness and are often unnoticed. Epileptic seizures are described by the term *ictus*
		From a Latin word meaning 'seized upon' (by the gods)	
Glioma	gli/o-	Glue	Glioma is the most common type of primary brain tumours in adults. They arise from glial tissue, most commonly astrocytic (star-shaped) tissue (astrocytoma). The second most common brain tumour is a *meningioma*, arising from the meninges. Brain tumours can be malignant or benign
	-oma	Tumour	

Continued

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Medical Terminology and Disorders Disorders of the Brain—cont'd

MEDICAL TERM	WORD PARTS	WORD PART MEANING OR DERIVATION	DESCRIPTION
Head injury			Due to trauma of the head and may or may not involve the brain. A *traumatic brain injury (TBI)* occurs when an external force traumatically injures the brain. TBI is a major cause of death and disability worldwide. Initially, brain injury is due to direct impact or by acceleration/deceleration alone; additional injury is sustained secondarily by injury-induced diminution of blood flow and increases in intracranial pressure. A mechanism-related classification system divides TBIs into closed and penetrating head injuries. A *closed head injury* occurs when the brain is not exposed, as in blunt trauma. A *penetrating (open) head injury* occurs when the penetrating object pierces the dura mater. Depending on its severity and location, TBI causes numerous deficits: physical, emotional, social and cognitive. Trauma to the head can cause bleeding and the formation of a *haematoma*, a swelling or tumour formed by a collection of blood. An *epidural haematoma* forms between the dura mater and the skull. A *subdural haematoma* forms under the dura mater
Hydrocephalus	hydro- -cephal/o-	Water Head	Hydrocephalus is also called 'water on the brain'. There is an abnormal accumulation of cerebrospinal fluid (CSF) within the cerebral ventricles that can cause enlargement of the cranium. The clinical presentation is dependent on chronicity and age. There is also a *normal pressure hydrocephalus (NPH)*, which develops more gradually in the elderly and is characterised by intermittent episodes of increased intracranial pressure
Infection		From the Latin word *inficere*, meaning transmission of disease by agency of air or water	The brain can be infected by a large number of microorganisms, most commonly bacteria and viruses. The pathogens cause inflammation of the surrounding tissue. *Encephalitis* is inflammation of the brain itself. *Meningitis* is inflammation of the meninges. A *brain abscess* is a collection of infectious material within the brain. Globally, bacterial meningitis is a major health concern in children. African children living in the 'meningitis belt' are particularly vulnerable
Neurotoxin	neur/o- -tox/o-	Nerve Poison	A neurotoxin is any natural or artificial substance that is toxic or harmful to nervous tissue. Commonly encountered neurotoxins include chemotherapeutic drugs, organic solvents, pesticides, cosmetics, heavy metals, alcohol ingestion and exposure to radiation. There are some naturally occurring neurotoxins, including beta-amyloid and glutamate
Palsy			A generalised term that refers to a loss of motor function. Three types of palsy are cerebral palsy, Bell's palsy and brachial palsy (Erb's palsy). *Cerebral palsy (CP)*, also called *spastic paralysis*, is a consequence of brain injury most often occurring in response to anoxic conditions around birth. All persons with CP experience muscle tightness and spasm causing limitations in muscle movement. *Bell's palsy* is due to inflammation or injury to the facial nerve (CN VII). *Brachial palsy* is usually caused by damage to the brachial plexus during a traumatic birth experience
Parkinson's disease (PD)		Named after James Parkinson, an English professor who wrote extensively about the disease	Parkinson's disease (PD), also called shaking palsy, is a dyskinesia that is classified as a movement disorder; it is due to diminished dopaminergic cell activity in the basal ganglia. PD is characterised by tremors (rest tremors) or shaking of the extremities, especially the hands and jaw; rigidity (muscle stiffness), *akinesia* (inability to initiate voluntary movement), *bradykinesia* (slow voluntary movement), stooped posture, shuffling or freezing gait, poor balance, slow speech and drooling. Cognitive abilities are generally preserved. *Parkinsonism* is a broad term that refers to disorders that present with similar symptoms. For example, prolonged use of antipsychotic drugs and brain injuries sustained by boxers cause symptoms similar to PD

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Chapter Overview

Summary Outline

The purpose of the nervous system is to bring information to the central nervous system, interpret the information and enable the body to respond to the information.

I. The Nervous System: Structure and Function
- **A.** Divisions of the nervous system
  - **1.** The central nervous system (CNS) includes the brain and the spinal cord
  - **2.** The peripheral nervous system includes the nerves that connect the CNS with the rest of the body
- **B.** Cells of the nervous system
  - **1.** Neuroglia (glia) support, protect and nourish the neurons
  - **2.** Neurons conduct the nerve impulse
- **C.** Neurons
  - **1.** Sensory, or afferent, neurons carry information towards the CNS
  - **2.** Motor, or efferent, neurons carry information away from the CNS towards the periphery
  - **3.** Interneurons are located in the CNS (make connections)
  - **4.** The three parts of a neuron are the dendrites, cell body and axon
- **D.** White matter and grey matter
  - **1.** White matter is the result of myelinated fibres
  - **2.** Grey matter is composed primarily of cell bodies, interneurons and unmyelinated fibres
  - **3.** Clusters of cell bodies (grey matter) are called nuclei and ganglia

II. Neurons Transmitting Information
- **A.** Nerve impulse
  - **1.** The electrical signal is called the action potential or nerve impulse
  - **2.** The nerve impulse is caused by the following changes in the neuron: polarisation, depolarisation and repolarisation
  - **3.** Initial depolarisation must reach threshold potential in order for the neuron to become fully depolarised
  - **4.** The nerve impulse results from the flow of ions: polarisation (outward leak of K^+), depolarisation (influx of Na^+) and repolarisation (outward flux of K^+)
  - **5.** The nerve impulse jumps from node to node as it travels along a myelinated fibre. Myelination increases the speed of the nerve impulse
  - **6.** The nerve impulse causes the release of the neurotransmitter at the synapse
- **B.** Synapse across neurons
  - **1.** The synapse is a space between two neurons
  - **2.** The nerve impulse of the first (presynaptic) neuron causes the release of neurotransmitter into the synaptic cleft. The neurotransmitter diffuses across the synaptic cleft and binds to the receptors on the second (postsynaptic) membrane. The activation of the receptors stimulates a nerve impulse in the second neuron

III. The Brain: Structure and Function
- **A.** Cerebrum
  - **1.** The right and left hemispheres are joined by the corpus callosum
  - **2.** The four main cerebral lobes are the frontal, parietal, temporal and occipital lobes. Functions of each lobe are summarised in Table 10.2
  - **3.** Large areas of the cerebrum, called association areas, are concerned with interpreting, integrating and analysing information
- **B.** Diencephalon
  - **1.** The thalamus is a relay station for most sensory tracts travelling to the cerebrum
  - **2.** The hypothalamus controls many body functions such as water balance, temperature and the secretion of hormones from the pituitary gland. It exerts an effect on the autonomic nervous system
- **C.** Brain stem
  - **1.** Brain stem: midbrain, pons and medulla oblongata
  - **2.** The medulla oblongata is called the vital centre because it controls the heart rate, blood pressure and respirations (the vital functions)
  - **3.** The vomiting centre is located in the medulla oblongata; it receives input directly and indirectly from activation of the chemoreceptor trigger zone (CTZ)
- **D.** Cerebellum
  - **1.** The cerebellum is sometimes called the little brain
  - **2.** The cerebellum is concerned primarily with the coordination of voluntary muscle activity
- **E.** Structures across divisions of the brain
  - **1.** The limbic system is sometimes called the emotional brain
  - **2.** The reticular formation alerts the cerebral cortex of sensory signals and regulates muscle tone in the resting state
  - **3.** The reticular activating system (RAS) is a specialised area of the reticular formation and is concerned with the sleep–wake cycle. It keeps us awake
  - **4.** Decreased activity of the RAS induces sleep
  - **5.** There are two types of sleep: REM and NREM
  - **6.** The memory areas handle immediate, short-term and long-term memory

IV. Protection of the central nervous system (CNS)
- **A.** Bone: cranium and vertebral column
- **B.** Meninges: pia mater, arachnoid mater and dura mater
- **C.** Cerebrospinal fluid (CSF): forms across the choroid plexus, circulates throughout the subarachnoid space and drains from the arachnoid villi into the blood of the dural sinuses
- **D.** Blood–brain barrier: prevents toxic substances in the blood from entering the nervous tissue of the brain and spinal cord

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Review Your Knowledge

Matching: Nerve Cells

Directions: Match the following words with their descriptions.

a. neurons
b. ganglia
c. CNS
d. neuroglia
e. axon terminal
f. axon
g. nodes of Ranvier
h. Schwann cell
i. dendrite
j. myelin

1. _____ Storage site for neurotransmitters
2. _____ Nerve glue; astrocytes and ependymal cells
3. _____ Part of the neuron that carries the action potential away from the cell body
4. _____ Nerve cells that transmit information by way of electrical signals called action potentials
5. _____ Composed of the brain and the spinal cord
6. _____ Clusters of cell bodies located outside of the CNS
7. _____ White insulating material that surrounds the axon; increases the speed at which the electrical signal travels along the axon
8. _____ Short segments of an axon that are not covered with myelin; allow for saltatory conduction
9. _____ A glial cell that makes myelin
10. _____ Tree-like structure of the neuron that receives information from another neuron and transmits that information to the cell body

Matching: Brain

Directions: Match the following words with their descriptions. Some words can be used more than once.

a. medulla oblongata
b. frontal
c. occipital
d. parietal
e. hypothalamus
f. temporal

1. _____ Cerebral lobe that performs executive functions and contains the primary motor cortex
2. _____ Part of the brain stem that is called the vital centre
3. _____ Part of the diencephalon that controls body temperature (thermostat) and endocrine function by its influence on the pituitary gland
4. _____ Location of the somatosensory area
5. _____ Cerebral lobe that contains the primary visual area
6. _____ Considered part of the diencephalon
7. _____ This structure descends through the foramen magnum as the spinal cord
8. _____ Considered part of the brain stem
9. _____ Cerebral lobe that contains the primary auditory area

Multiple Choice

1. The precentral gyrus is:
a. located in the parietal lobe
b. the primary motor cortex
c. the primary visual cortex
d. a brain-stem structure

2. Which of the following is *not* descriptive of Broca's area?
a. Located in the frontal lobe
b. Concerned with motor speech
c. Most often located in the left cerebral hemisphere
d. Concerned only with sensory functions

3. Which of the following statements is true?
a. The medulla oblongata is a cerebral structure
b. The hypothalamus is a brain-stem structure
c. The medulla oblongata descends as the spinal cord
d. The midbrain, pons and medulla oblongata are supratentorial structures

4. Which of the following is *not* descriptive of the medulla oblongata?
a. It is a brain-stem structure
b. It is called the vital centre
c. It is sensitive to the effects of narcotics (opioids)
d. It performs executive functions

5. The postcentral gyrus:
a. is located in the parietal lobe
b. controls all voluntary motor activity
c. is the home of Broca's area
d. contains the primary visual cortex

6. Cerebrospinal fluid (CSF):
a. drains out of the subarachnoid space into the choroid plexus
b. circulates within the subarachnoid space
c. looks like blood
d. flows up the central canal into the fourth, third and lateral ventricles

7. Which of the following relationships is accurate?
a. Temporal lobe: vision
b. Frontal lobe: somatosensory (touch, pressure, pain)
c. Occipital lobe: vision
d. Parietal lobe: hearing

8. Neuroglia:
a. are classified as sensory and motor
b. include astrocytes, oligodendrocytes, Schwann cells and ependymal cells
c. fire action potentials when stimulated
d. contain dendrites and axons

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9. Depolarisation and repolarisation:
   a. are both caused by the movement of Na^+ into the neuron
   b. are phases of the action potential
   c. occur only in the neuroglia
   d. are both caused by the movement of K^+ out of the neuron
10. Activation of the emetic centre or CTZ:
   a. elevates blood pressure
   b. lowers body temperature
   c. causes diaphoresis
   d. induces vomiting
11. Characteristics of the hypothalamus include which of the following?
   a. Part of the diencephalon
   b. Synthesises hormones (antidiuretic hormone and oxytocin)
   c. Controls pituitary gland activity
   d. All of the above
12. Schwann cells:
   a. line the ventricles and help in the secretion of cerebrospinal fluid
   b. are found in all glial cells
   c. produce myelin sheath for neurons located within the peripheral nervous system
   d. secrete cerebrospinal fluid
13. The nodes of Ranvier:
   a. are cells that secrete cerebrospinal fluid
   b. are glial cells
   c. are axonal sites covered by fatty insulation
   d. are areas of the axonal membrane that are not covered by a myelin sheath
14. Which of the following is true with regard to the nerve impulse?
   a. The outward leaky diffusion of K^+ and trapped anions within the cell are responsible for the resting membrane potential.
   b. The rapid efflux of K^+ from the neuron is responsible for depolarisation.
   c. The rapid influx of Na^+ is responsible for repolarisation.
   d. The rapid efflux of Na^+ is responsible for repolarisation.
15. Which of the following describes the precentral and post-central gyri?
   a. Right and left hemispheres
   b. Motor and sensory
   c. Supratentorial and infratentorial
   d. Vision and hearing

Figure Review

1. Which of the following is correct according to Fig. 10.4?
   a. The electrical signal runs from the axon terminals, along the axon, to the cell body and dendrites.
   b. The electrical signal runs from the cell body, along the axon, to the axon terminals.
   c. Nodes of Ranvier are myelinated axonal membranes.
   d. All dendrites are myelinated.
2. Which of the following is correct according to Fig. 10.5?
   a. Repolarisation is characterised by a return of the membrane potential to its resting state.
   b. The inside of the repolarised neuron is (+).
   c. The inside of the depolarised neuron is (–).
   d. Depolarisation is characterised by a return of the membrane potential to its resting state.
3. Which of the following is correct according to Fig. 10.6?
   a. The action potential only refers to attainment of threshold potential.
   b. The action potential refers to the depolarisation and repolarisation of the cell.
   c. The inside of the cell becomes more negative as the membrane potential moves from –70 mV to –55 mV.
   d. The threshold potential is a characteristic of the re-polarising phase of the resting membrane potential.
4. Which of the following is correct according to Fig. 10.7?
   a. Panel B illustrates the influx of Na^+ and depolarisation.
   b. Panel B illustrates the influx of Na^+ and repolarisation.
   c. Panel C illustrates the influx of K^+ and depolarisation.
   d. Panel C illustrates the efflux of K^+ and depolarisation.
5. Which of the following is correct according to Fig. 10.8?
   a. The action potential travels from the axon terminal to the cell body.
   b. The action potential (NI-1) at point A depolarises the adjacent membrane, thereby causing NI-2 at point B.
   c. The electrical events at point C cause an action potential to form at point A.
   d. The electrical events at point D cause an action potential to form at point B.
6. Which of the following is illustrated in Fig. 10.9?
   a. The formation of a nerve impulse at each node.
   b. The effect of myelination on conduction velocity (the speed at which the nerve impulse travels along the axon).
   c. Saltatory conduction.
   d. All of the above.
7. Which of the following is correct according to Fig. 10.10?
   a. Acetylcholine (ACh) is an enzyme that inactivates acetylcholinesterase.
   b. Acetylcholinesterase inactivates ACh immediately after its release from the axon terminal.
   c. The receptors on the membrane of neuron B are activated by ACh.
   d. Both acetylcholine and acetylcholinesterase are stored within the vesicles of the axon terminal.
8. Which of the following is correct according to Fig. 10.11?
   a. The diencephalon is a cerebral structure.
   b. The cerebellum is a brain-stem structure.
   c. The cerebrum is the largest and most superior of the areas of the brain.
   d. The brain stem is separated from the spinal cord by the cerebellum.

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9. Which of the following is correct according to Fig. 10.12?
   a. The primary somatosensory area is located in the precentral gyrus.
   b. The primary motor area is located in the postcentral gyrus.
   c. Broca's area is concerned with motor speech and is located in the frontal lobe.
   d. The primary auditory cortex and the auditory association area are located in the occipital lobe.
10. According to Fig. 10.13, the homunculus:
   a. is a sensory homunculus.
   b. lies over the cerebellum.
   c. depicts the function of the brain-stem structures.
   d. indicates that most of the precentral gyrus is dedicated to the motor activity of the face and hands.
11. Which of the following is correct according to Fig. 10.14?
   a. The pituitary gland is a brain-stem structure.
   b. The thalamus and hypothalamus are cerebral structures.
   c. The midbrain, pons and medulla oblongata are brain-stem structures.
   d. The thalamus extends downwards as the spinal cord.
12. Which of the following is correct according to Fig. 10.15?
   a. The arachnoid villi protrude into the dural sinuses.
   b. Cerebrospinal fluid circulates within the subarachnoid space.
   c. The dural sinuses are filled with blood.
   d. All of the above.
13. Which of the following is correct according to Fig. 10.16?
   a. Cerebrospinal fluid is secreted by the arachnoid villi and drained by the choroid plexus.
   b. The arachnoid villi protrude into the lateral ventricles, where they are bathed in cerebrospinal fluid.
   c. Cerebrospinal fluid is secreted by the choroid plexus into the dural sinuses.
   d. The cerebral aqueduct drains cerebrospinal fluid from the third ventricle.

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