1 Introduction

CHAPTER OUTLINE

Objective

This book was written primarily for the veterinary student and secondarily for the veterinary practitioner. This textbook provides a guideline for a systematic approach to the evaluation of the nervous system and to the recognition of neurologic dysfunction in a veterinary patient. It is organized to provide the veterinary student with an anatomic basis and sufficient information about the development, organization, and function of the nervous system to be able to understand and diagnose common disorders of the nervous system of domestic animals. For the most part, these disorders are discussed in the chapter that describes the functional system primarily affected by the disorder.

Accurate Diagnosis

The major objective of this book is to teach enough of the morphologic and physiologic features of the nervous system to enable the student to accurately localize the lesion in the nervous system using the clinical neurologic examination. This is the *anatomic* diagnosis. The *differential* diagnosis depends entirely on the anatomic diagnosis, and that, in turn, determines the ancillary diagnostic procedures that will be prioritized to arrive at the most accurate presumptive clinical diagnosis and the subsequent treatment selection and prognosis.

The diagnosis of clinical neurologic disorders starts with recognition of the problem—the clinical signs exhibited by the patient and your neurologic examination findings. This visual and hands-on experience is difficult to learn by reading text descriptions. Direct contact with the affected patient is the ideal teaching model but is impractical in a teaching environment. The most effective alternative is to visualize the clinical signs using video technology. This fifth edition, like the third and fourth, includes a companion website consisting of a large number of videos that provide the student and clinician with the classic appearance of the common disorders of the nervous system of domestic animals.

The anatomic diagnosis is determined by the nature of the problem, that is, the clinical signs that you have observed. You should first attempt to determine whether all the clinical signs can be explained by a lesion at one site in the nervous system—a focal lesion—because they are more common than multifocal or diffuse disorders. It is imperative to be as precise as possible in making an anatomic diagnosis. It is not sufficient to list "brain" as the anatomic diagnosis; a more precise location (e.g., prosencephalon, midbrain, pons, medulla, or cerebellum) should be sought. On the basis of this anatomic diagnosis, you will next establish a list of disorders that must be able to affect the anatomic location of the lesion. This is the differential diagnosis. For example, an intervertebral disc herniation is a differential diagnosis of a lesion affecting the thoracolumbar spinal cord segments. You will learn various ways to remind yourself of broad categories of disorders to consider. One such mnemonic is the MIIND system (malformation, injury, inflammation, neoplasia, and degeneration).

MALFORMATION

Malformations are disorders that result from abnormal development of the nervous system.

INFLAMMATION

Inflammation involves a pathologic process and a reaction of blood vessels and tissues to physical, chemical, and biologic agents—the reaction of a tissue to an irritant. In the nervous system, this commonly refers to the reaction of tissues to a microorganism or an immune-mediated response in the absence of infection. Suppurative inflammation is characterized by a neutrophilic response and the products of tissue necrosis and inflammatory cells often caused by a bacterium, protozoan, or fungus. Nonsuppurative inflammation is characterized by a lymphocytic or monocytic response and is usually caused by a viral agent or an immune system abnormality.

INJURY

Injury occurs when nerve tissue undergoes traumatic disturbance derived from external or internal sources. These cause acute or chronic displacements and disruptions or vascular impairment of the nervous tissue, which may result in hemorrhage, edema, or parenchymal necrosis.

NEOPLASIA

Neoplasia is uncontrolled growth of cells. Primary central nervous system (CNS) neoplasms include the uncontrolled growth of nervous tissue cells (neurons, glia, and ependymal cells) as well as nonnervous tissues such as choroid plexus neoplasms. These have an *intraparenchymal* location. Metastatic neoplasia affecting the nervous system is the spread of primary neoplasms in other body tissues to the nervous system. These may have an intraparenchymal or extraparenchymal location. Neoplasms that are external to the nervous system, that is, those that are *extraparenchymal*, cause injury to the nervous system parenchyma, typically by compression. An example is a meningioma. (Note that we have chosen to use the terms *extraparenchymal* and *intraparenchymal*, as opposed to *extraaxial* and *intraaxial*, because the latter are directional terms, not structural.)

DEGENERATION

Degenerations include the deterioration of cells from lack of blood supply (ischemia), abnormal cellular metabolism caused by an inherited cellular defect, exposure to exogenous toxins, and abnormalities in other body systems (kidney disorders with uremia, diffuse liver disorders with hyperammonemia, cardiorespiratory disorders with hypoxia). *Abiotrophy* is cell degeneration caused by an intrinsic defect in the essential metabolism necessary for the survival and function of that cell, the neuron.

Do not forget to consider the breed of your patient and the possibility of an inherited disorder encountered in that breed. You will prioritize (rank in order from most likely to least) these disorders in your differential diagnosis based on signalment, history, course of clinical signs, and characteristics of the various disorders being considered. For example, a young dachshund with an intervertebral disc herniation affecting the thoracolumbar spinal cord segments will likely have an acute onset and progressive course of clinical signs.

Based on this ranking in differential diagnosis, the most useful ancillary procedures will be selected to further confirm or exclude the diagnosis under consideration. This selection is especially critical now that cross-sectional imaging with computed tomography and magnetic resonance imaging are readily available to veterinarians. Cross-sectional imaging requires general anesthesia, and the costs to the patient's owner are considerable. Therefore it is crucial that the correct anatomic diagnosis is made before the ancillary procedures are selected. Ultimately, your ability to establish a correct anatomic diagnosis will enable you to define the most appropriate diagnostic regimen to arrive at a definitive etiologic diagnosis. Only with an accurate etiologic diagnosis can you offer the most appropriate therapy and thereby achieve the best outcome.

Neuron

The nervous system is composed of primary functional cells (neurons) and supporting cells, which include the glia and the ependyma. In this text the *neuron* is defined as a cell consisting of a dendritic zone, axon, cell body, and telodendron. The *dendritic zone* is the receptor portion, where a stimulus from the internal or external environment is converted into an impulse in the neuron. The *axon* is the cell process composed of neurofilaments that course from the dendritic zone to the telodendron. The *telodendron* is the termination of the neuron where the impulse leaves the neuron. It is often referred to as the *synapse*. This synapse may lie at an effector organ or at another neuron. The cell body consists of the nucleus and the major organelles necessary for the neuron to function and, depending on the neuron type, may be located in a different region along the axon. For example, a sensory neuron in the peripheral nervous system for general proprioception may have its dendritic zone in a neuromuscular spindle in a skeletal muscle, where it is stimulated by stretching of the muscle. The axon courses toward the spinal cord through a specific nerve and then through the dorsal or ventral branch of one of the spinal nerves and into its dorsal root. It then enters the spinal cord at the dorsolateral sulcus and passes into the dorsal gray column of that spinal cord segment to synapse on a second neuron within that gray column. The telodendron is the nerve ending at the synapse on this second neuron. The neuronal cell body is located in the spinal ganglion associated with the dorsal root that the axon coursed through to reach the spinal cord. It is actually intercalated in the axon at this point (Fig. 1.1).

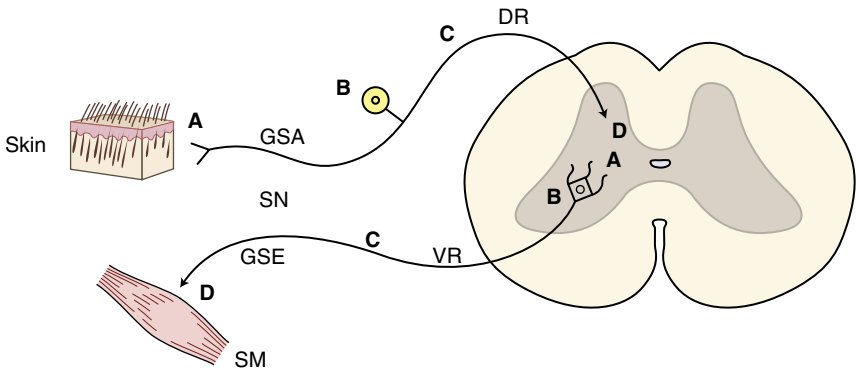

Fig. 1.1 Diagram of a general somatic afferent (*GSA*) neuron and a general somatic efferent (*GSE*) neuron in a spinal nerve (*SN*). *A*, Dendritic zone; *B*, cell body; *C*, axon; *D*, telodendron; *DR*, dorsal root; *SM*, skeletal muscle; *VR*, ventral root.

The dendritic zone and the cell body of a motor neuron that innervates a skeletal muscle are closely associated and are located in the ventral gray horn of a segment of the spinal cord. The axon leaves the cell body in this gray matter and courses through the white matter of that segment and emerges through the ventrolateral sulcus to enter the ventral root of that segment. It continues into the spinal nerve of that segment and its dorsal or ventral branch and then travels in a specific nerve to reach the skeletal muscle cells being innervated. Here, the axon ends in a telodendron at the neuromuscular ending in a motor end plate.

Within the CNS a neuron of the dorsal spinocerebellar tract is an example of a sensory or afferent neuron to the cerebellum. Its dendritic zone and cell body are closely associated in a nucleus in the dorsal gray horn of the spinal cord. The impulse is initiated here by a synapse with the telodendron of a sensory general proprioceptive neuron of the peripheral nervous system. The axon courses through the gray matter into the white matter of the lateral funiculus to join other axons in a tract on the dorsal superficial surface of the lateral funiculus. This axon continues cranially in this dorsal spinocerebellar tract. It traverses the portion of the spinal cord cranial to the spinal cord segment where it originated and then continues into the medulla, where it enters the cerebellum via the caudal cerebellar peduncle. It courses through the cerebellar medulla and into the white matter of a cerebellar folium. It enters the adjacent granular layer of the cerebellum and terminates in a telodendron that synapses with the dendritic zone of a granule cell neuron.

Within the CNS the Purkinje neuron of the cerebellum is an example of an efferent neuron in the cerebellar cortex. Its dendritic zone consists of a branched structure located in the molecular layer of the cerebellar cortex on the surface of a folium. Here the telodendria of the granule cell neurons synapse at sites on these branches to initiate the impulse in the Purkinje neuron. The cell body is located in the Purkinje neuronal layer of the cerebellar cortex. The axon arises from this cell body and courses through the granular layer into and through the white matter of that cerebellar folium and enters the white matter of the cerebellar medulla. Here, the axon ends in a telodendron on the dendritic zone of another efferent neuron located in a nucleus of the cerebellar medulla.

Functional Systems

This text is organized primarily by functional systems rather than by regions of the nervous system, by the chief clinical neurologic complaint, or by disease processes. It is our opinion that this is the most effective way to teach the organization of the nervous system and provide the basis for understanding the disorders that affect the various components of the nervous system in a systematic and understandable manner. Most of these functional systems are derived from a classification of the peripheral nervous system based on its functional components. The sensory portion has extensive components in the CNS. The classification is outlined in Table 1.1.

SENSORY (AFFERENT) SYSTEM

The sensory, or afferent, portion of the peripheral nervous system is classified on the basis of the location of the dendritic zone in the body. This is the site of the origin of the impulse.

Somatic Afferent System

The somatic afferent system has its dendritic zone on or near the surface of the body derived from the somatopleura, where it receives the various stimuli from the external environment.

General Somatic Afferent System. The general somatic afferent (GSA) system comprises the neurons distributed primarily by the fifth cranial nerve to the surface of the head and all the spinal nerves to the surface of the body and limbs that are sensitive to touch, temperature, and noxious stimuli.

Special Somatic Afferent System. The special somatic afferent system involves specialized dendritic zone receptor organs limited to one area deep to the body surface but stimulated by changes in the external environment. These include light to the eyeball (cranial nerve II) and sound waves indirectly to the membranous labyrinth of the inner ear (cranial nerve VIII, cochlear division).

Visceral Afferent System

The visceral afferent system has its dendritic zone in the wall of the various viscera of the body. This tissue is derived mostly from splanchnopleura and is stimulated by changes in the internal environment.

General Visceral Afferent System. The general visceral afferent system is composed of neurons distributed by the seventh, ninth, and tenth cranial nerves to visceral structures in the head

TABLE 1.1 Functional Classification of the Nervous System

System	Function and Anatomic Location
SENSORY (AFFERENT) SYSTEM	
Somatic	
General	Temperature, touch, noxious stimuli All spinal nerves, cranial nerve V
Special	Vision: cranial nerve II Hearing: cranial nerve VIII
Visceral	
General	Organ content, distention, chemicals Spinal nerve splanchnic branches Cranial nerves VII, IX, X
Special	Taste: cranial nerves VII, IX, X Olfaction: cranial nerve I
Proprioception	
General	Muscle and joint movement All spinal nerves, cranial nerve V
Special	Vestibular system: cranial nerve VIII
MOTOR (EFFERENT) SYSTEM	
Somatic	
General	Striated skeletal muscle All spinal nerves Cranial nerves III, IV, V, VI, VII, IX, X, XI XII
Visceral	
General	Smooth and cardiac muscle and glands Sympathetic: all spinal nerves, splanchnic nerves Parasympathetic: sacral spinal nerves Cranial nerves III, VII, IX, X

and by the tenth cranial nerve and spinal nerves to the viscera of the body cavities and blood vessels throughout the neck, trunk, and limbs. This widely distributed system is stimulated primarily by the distention of visceral walls and chemical changes.

Special Visceral Afferent System. The special visceral afferent system contains the neurons in the seventh, ninth, and tenth cranial nerves, whose dendritic zones are limited to the specialized receptors for taste, and the first cranial nerve, whose dendritic zones are localized in the caudal nasal mucosa for olfaction.

Proprioception System

The modality of general proprioception is sometimes included in the GSA system. In this text, we consider it a separate system because of its clinical significance. Disorders that affect this system express clinical signs different from those that affect the GSA system. Proprioception is the system responsible for detecting changes in the position of the head, neck, trunk, and limbs.

General Proprioception System. The dendritic zones of the general proprioception system are widely distributed in receptor organs located in muscles, tendons, and joints deep to the body surface. This system is distributed widely throughout all the spinal nerves and the fifth cranial nerve. The receptors are sensitive to changes in the lengths and positions of the structures they innervate.

Special Proprioception System. The special proprioception system's dendritic zones are limited to receptors specialized to respond to positions and movements of the head. They are located in a portion of the membranous labyrinth of the inner ear. These neurons concerned with the orientation of the head in space are in the vestibular division of the vestibulocochlear nerve (cranial nerve VIII).

MOTOR (EFFERENT) SYSTEM

The motor, or efferent, portion of the peripheral nervous system is classified based on where the motor neuron terminates, which is the site of the telodendron. This peripheral motor system is also referred to as the lower motor neuron because it is the final neuron to innervate the muscle cell. The efferent system has somatic and visceral components.

General Somatic Efferent System

In the general somatic efferent (GSE) system, the telodendron is located in voluntary striated skeletal muscle through the entire body derived from somatic mesoderm, somites, and head somitomeres. The cell body and dendritic zone of these GSE neurons are in the spinal cord ventral gray horn and in the nuclei in the brainstem. Their axons are in the ventral root and spinal nerves or in cranial nerves, and they course through variously named nerves to terminate in a telodendron in a muscle cell at the neuromuscular ending (junction). These GSE neurons are found in all the spinal nerves and in all the cranial nerves except cranial nerves I, II, and VIII.

General Visceral Efferent System

The general visceral efferent (GVE) system has its telodendria in involuntary smooth muscle of viscera derived from splanchnic mesoderm as well as blood vessels, cardiac muscle, and glands. This system is the lower motor neuron of the autonomic nervous system, which has components in all segments of the brain and spinal cord. In some texts, the GVE system is considered the entire autonomic system; we believe that to be an inappropriate concept that defies the true functional totality of this autonomic system, which includes peripheral afferent components and a plethora of nuclei and tracts at all levels of the CNS.

The GVE system, unlike the GSE system, is a two-neuron system in that two neurons exist between the CNS and the target organ. A synapse occurs in a ganglion between these two neurons. The two divisions of this system are the sympathetic and parasympathetic divisions, which are further described in Chapter 7, which is devoted to the GVE system. These GVE neurons are distributed in cranial nerves III, VII, IX, and X, and in all the spinal nerves.

In the first three editions of this text and in older books of developmental anatomy, a special visceral efferent system was described for the innervation of striated skeletal muscle in the head derived from branchial arch mesoderm. This classification was deleted from the fourth edition and does not appear in this fifth edition because no functional difference exists between skeletal muscle of the head and the muscles in the rest of the body. All striated skeletal muscle of the head is now considered to be innervated by the GSE system.

Further Reading

For further reading, we highly recommend the textbooks listed in the Suggested Readings at the end of this chapter. For all aspects of canine neuroanatomy, the most extensive and thorough descriptions are found in the fifth edition of *Miller and Evans' Anatomy of the Dog* by John Hermanson, Alexander de Lahunta, and Howard Evans. From our perspective, this text should be considered the gold standard. We have found several other texts, although out of print, to be useful. The text by Tom Jenkins, *Functional Mammalian Neuroanatomy,* is an easy read, has many simplified line drawings of various neurologic concepts, and is based primarily on the dog. For the study of brain sections in all three planes, *The Brain of the Dog in Section* by Marcus Singer is unsurpassed. This is a superb text for correlation with magnetic resonance images. Images from Singer's textbook are available online at http://www.brainmaps.org. Additionally, *Illustrated Veterinary Anatomical Nomenclature*, edited by Oskar Schaller and Gheorghe M. Constantinescu, provides illustrations complementary to *Miller's Anatomy of the Dog*, along with anatomic illustrations of other species.

For further reading in veterinary clinical neurology, the Suggested Readings provided are all well written and provide thorough coverage of their respective areas. Cheryl Chrisman's texts focus on small animals and are usefully organized by chief complaints of patients. Kyle Braund's text is organized like a dictionary and is useful for looking up short, succinct reviews of neurologic problems of domestic animals. A wide range of species is included in the fifth edition of the *Handbook of Veterinary Neurology*, by Mike Lorenz, Joan Coates, and Marc Kent, although their personal experience is mostly with small animals. The only text in veterinary neurology that focuses on large animals is *Large Animal Neurology* by Joe Mayhew. This is a superb book that represents his extensive personal experience. *Equine Neurology*, edited by Martin Furr and Stephen Reed, is a useful text that focuses on the horse.

The original textbook of veterinary neurology written by Ben Hoerlein, which included an extensive section on surgical and medical treatment, was revised by John Oliver and Joe Mayhew and was expanded to include some large animal neurology. *A Practical Guide to Canine and Feline Neurology* by Curtis Dewey and Ronaldo da Costa provides a thorough review of these species. For neurosurgical procedures involving the vertebral column and spinal cord, the textbook by Nick Sharp and Simon Wheeler details the contemporary aspects of neurosurgery for small animals. This text is supported by excellent diagrams and photographs.

Two textbooks are devoted to veterinary neuropathology. *Veterinary Neuropathology,* by Brian Summers, John Cummings, and Alexander de Lahunta, is now out of print. In addition to descriptive neuropathology, this text includes considerable clinical correlations as well as descriptions of pathogenesis. *Veterinary Neuropathology: Essentials of Theory and Practice,* by Marc Vandevelde, Robert Higgens, and Anna Oevermann, provides a succinct but thorough discussion of the subject. For nervous system development and malformations, refer to *The Embryology of Domestic Animals: Developmental Mechanisms and Malformations,* by Drew Noden and Alexander de Lahunta.

SUGGESTED READINGS

Domestic Animal Neuroanatomy

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