

Nervous system (vertebrate)

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A coordinating and integrating system which functions in the adaptation of an organism to its environment. An environmental stimulus causes a response in an organism when specialized structures, receptors, are excited. Excitations are conducted by nerves to effectors which act to adapt the organism to the changed conditions of the environment. In animals, humoral correlation is controlled by the activities of the endocrine system. This article considers the morphology, histology, and embryology of the nervous system, including the brain and cranial nerves, and embryology of the sense organs.

Comparative Morphology

The brain of all vertebrates, including humans, consists of three basic divisions: prosencephalon, mesencephalon, and rhombencephalon (**Fig. 1**). Newer experimental methods for exploring the connections and functions have resulted in much information on the evolution of this system. The indication is that these divisions of the vertebrate brain have evolved along several functional lines and perform very different functions.

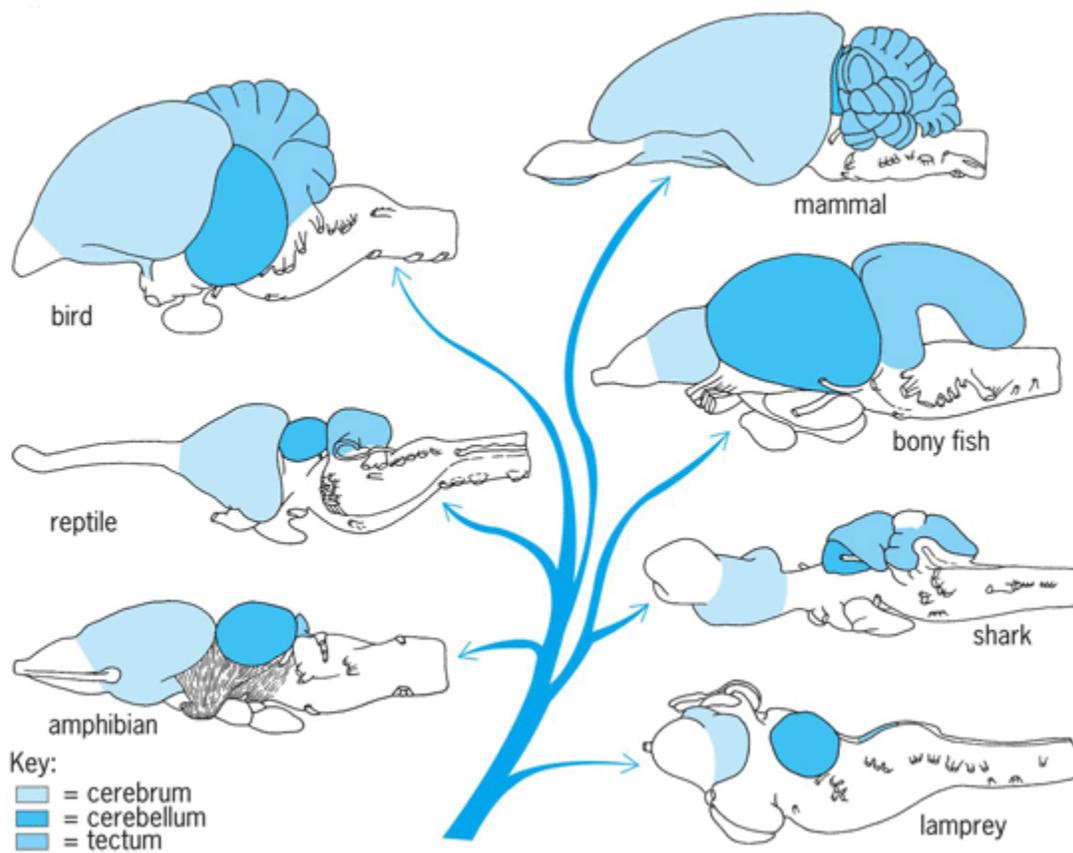


Fig. 1 Lateral views of several vertebrate brains showing evolutionary relationships.

The comparative neuroanatomist is interested in the variation among the vertebrate brains, and attempts to understand how they evolved from common ancestors and to clarify the functional significance of their variations. It is necessary that the neuroanatomist recognize structures in different brains among living forms which have arisen from one or more structures in an ancestral brain. This search for homologous structures is complicated by the fact that brains do not fossilize; thus the comparative anatomist can only infer what the possible structure of the brain in ancestral vertebrates was like. It is thought that the brain of ancestral vertebrates was much simpler than those of living forms, but neuroanatomists suggest different views regarding the brain's evolution.

One view holds that structures have arisen afresh with no traces in lower living vertebrates. The second view proposes that the simpler ancestral brain possessed very generalized connections which have either been lost or have become specialized in living vertebrates. The latter idea seems to be closer to the truth and is more in line with what is known about evolution of other vertebrate body systems.

The nervous system of ancestral vertebrates apparently consisted of a single hollow neural tube, dorsally placed and running the length of the animal, that was probably structured in a manner similar to the spinal cord in living vertebrates (**Fig. 2**). It consisted of a central gray region which contained most of the cell bodies of the neurons and was surrounded by a superficial white region containing the axons and dendrites of the neurons running to and from the tube. Each region of the tube was primarily concerned with the functions of that immediate region of the body to which its nerves projected. Neural functions were mediated at a segmental level rather than specialized in one specific region. Each region of the neural tube also contained neural cells which interconnected adjacent regions. This primitive condition still persists in a few living forms.

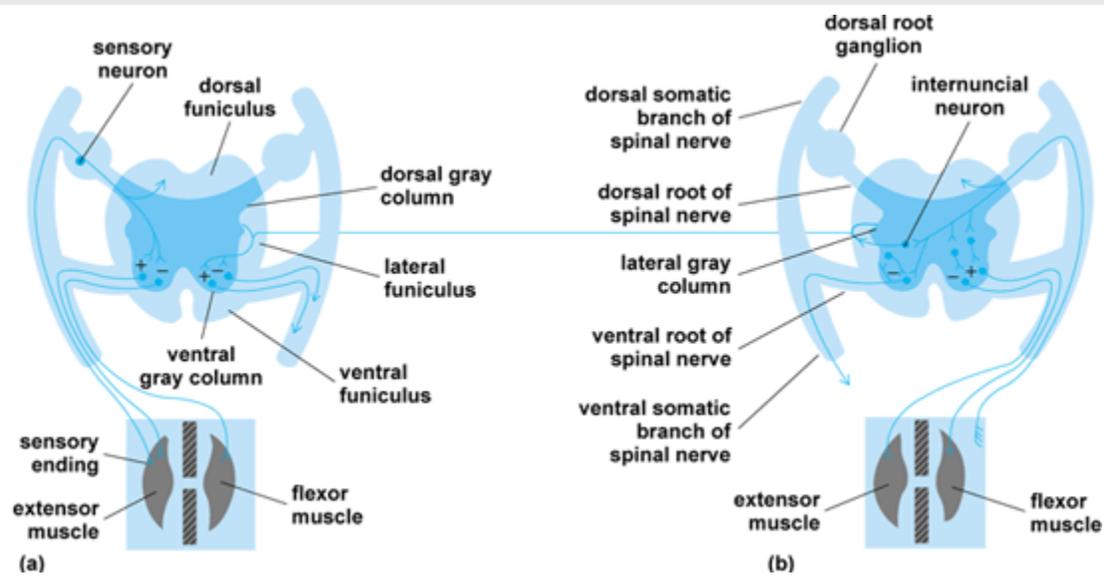


Fig. 2 Spinal cord diagram. (a) Monosynaptic arcs. (b) Multisynaptic arcs.

As vertebrates evolved, structures in the head region became specialized for sensing the outside world and capturing food. This specialization was reflected in the neural tube, and its anterior region enlarged to permit analysis of the environment and integration of behavior. This enlargement of the neural tube is called a brain, and its divisions represent regions of different specialization. Each of the three primitive brain divisions was concerned with analysis and integration of a single type of sensory information. The rhombencephalon analyzed changes in the flow and pressure of water on an animal; the mesencephalon analyzed changes in the pattern and intensity of light; and the prosencephalon analyzed changes in the chemical composition of water. All vertebrates use these three types of information as clues in regulating their behavior. However, major changes in the structures that analyze this information appear to be correlated with increased quality of perception and more centralized control of movement. This has occurred by an increase in the number of analyzing units between the sensory mechanisms and the response mechanisms. This increase permits a delay in the response of a vertebrate to sensory cues and thus permits greater analysis of information contained in the clues. Presumably, this has value to an animal in that it results in responses which have a higher degree of survival value.

The evolution of the central nervous system is described below as the evolution of functional systems or patterns whose specialization is reflected by the concomitant specialization of brain divisions. The individual divisions or patterns of the brain do not function separately to bring about a final response; rather, each pattern acts on a common set of connections in the spinal cord. The common spinal connections are first described and then used as a basis for understanding the action of the brain patterns upon them.

Spinal patterns

These are the final common patterns used by all higher brain pathways to influence all organs of the body. These reflexes are divided into two basic patterns: the monosynaptic arc and the multisynaptic arc.

The monosynaptic arc, or myotatic reflex, maintains tonus and posture in vertebrates and consists of two neurons, a sensory and a motor neuron. The sensory neuron possesses a sensory ending in the extensor muscle (**Fig. 2a**), and this nerve ending is stimulated when the muscle is stretched by the pull of gravity. The axon of the sensory neuron projects to the motor neuron of the extensor muscle. This motor neuron is located in the ventral, gray region of the spinal cord, and its axon projects back to the extensor muscle, thus completing the arc.

When the extensor muscle is stretched, the sensory ending of the sensory neuron is stimulated, and this stimulation is

transmitted to the cell body of the sensory neuron. The sensory cell body then transmits a signal to the motor neuron of the extensor muscle, which will cause the motor neuron to transmit. At the same time, the sensory neuron causes the motor neuron of the flexor muscle to decrease its transmission. These processes are indicated respectively by plus and minus signs in **Fig. 2**. The result is that the extensor motor neuron causes the extensor muscle to contract, and the flexor motor neuron causes the flexor muscle to relax. This extends the limb and supports the weight of the animal. The sensory neuron of the extensor muscle also sends an axonic collateral to brain centers where the sensory information is analyzed.

The multisynaptic arc, or flexor reflex, is the pattern by which an animal withdraws a part of its body from a noxious stimulus. Stimulation of the skin or muscle causes a sensory neuron to transmit a signal causing motor neurons, via internuncial neurons, to increase the contraction of flexor muscles and decrease the contraction of extensor muscles. The result is movement of a limb or body part away from the stimulus. Both sensory neurons and internuncial neurons send information to brain centers (**Fig. 2**).

The multisynaptic arc also gives rise to a pattern that results in alternating movement of a forelimb and the diagonal hindlimb. This is termed reflex stepping. Thus coordinated limb movement is based on a connective pattern of neurons at the spinal level.

The structure of the spinal cord and its connections are basically similar among all vertebrates, and myotatic and flexor reflexes occur in all vertebrates. The major evolutionary changes in the spinal cord have been the increased segregation of cells and fibers of a common function from cells and fibers of other functions and the increase in the length of fibers which connect brain centers with spinal centers. See also: **[Postural equilibrium \(/content/postural-equilibrium/082600\)](#)**

Medullar patterns

The rhombencephalon of the brain is subdivided into a roof, or cerebellum, and a floor, or medulla oblongata. The medulla is similar to the spinal cord and is divided into a dorsal sensory region and a ventral motor region. The sensory region consists of two longitudinal columns; a dorsal, somatic sensory column and a ventral, visceral sensory column. The ventral motor region of the medulla is similarly divided into two longitudinal columns, a dorsal, visceral motor column and a ventral, somatic motor column. These divisions occur in the spinal cord and continue through the medulla into the tegmentum, the floor of the mesencephalon.

The medulla is an integrating and relay area between higher brain centers and the spinal cord. Primitively, the columns were composed of neurons scattered throughout the length of the medulla. With the specialization of the vertebrate head, the columns broke up into a series of nuclei that formed the neural elements for reflex circuits of the cranial nerves innervating the organs of the head and gills.

In addition to these nuclei and their connections, the medulla consists of both ascending and descending pathways to and from higher brain centers. The nuclei of the medulla shift with reference to one another, and their relative volumes change as specialization in gill and feeding mechanisms occurs. However, the same basic connections occur throughout vertebrates. The tracts which pass through the medulla between higher brain centers and the spinal cord become more distinguishable as their boundaries become more compact in relation to other tracts. The tracts, like the nuclei of the medulla, may change volume in response to specialization.

Cerebellar patterns

The cerebellum has had a varied history of development in vertebrates. In all vertebrates, the cerebellum is divided into two major divisions: the two lateral flocculonodular lobes, and a central corpus cerebelli. The flocculonodular lobes are

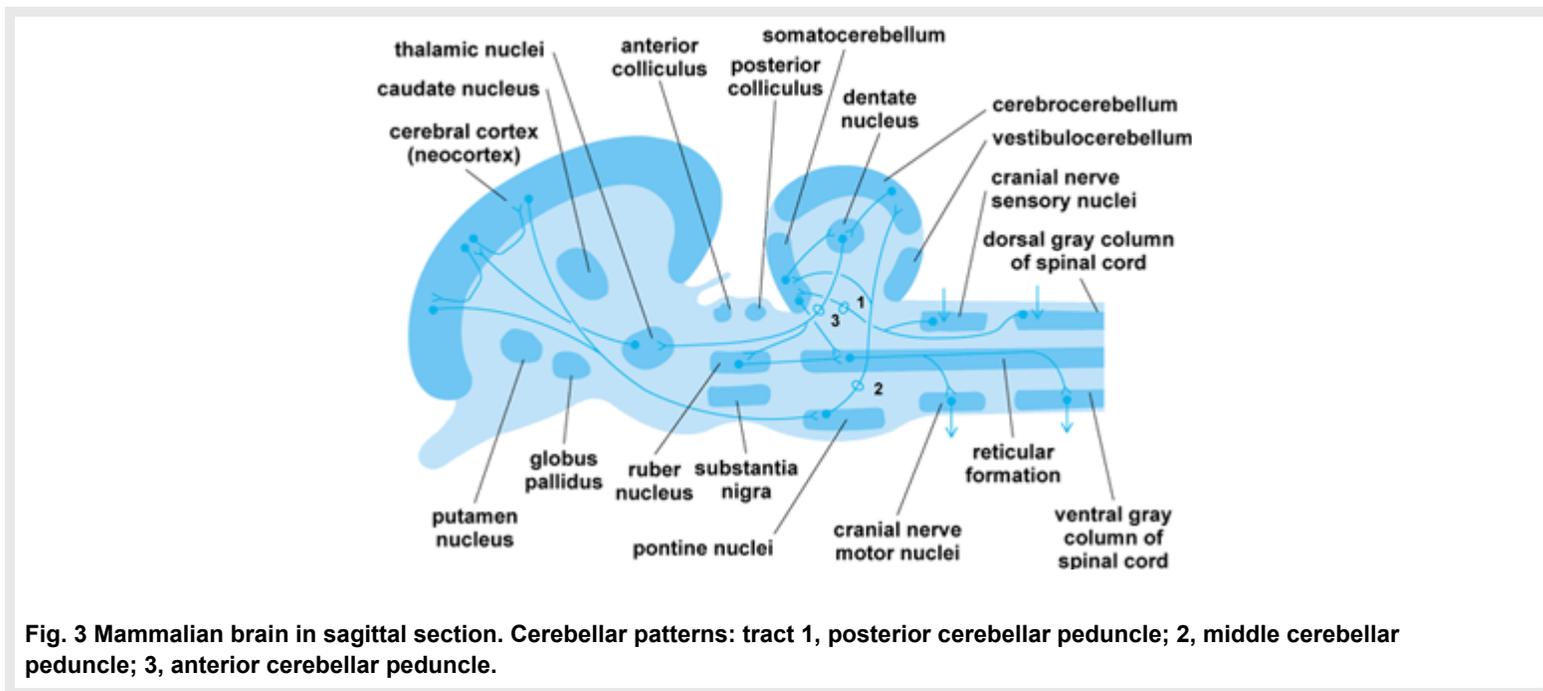
functionally referred to as the vestibulocerebellum and regulate vestibular reflexes underlying posture. The corpus cerebelli is subdivided into two lateral zones, the cerebrocerebellum and a central zone, the somatocerebellum. In mammals, the lateral zones regulate corrective reflexes of posture and time muscular contractions of voluntary actions. The medial zone in mammals regulates reflex tonus of postural muscles by acting on the myotatic reflex.

The flocculonodular lobes, or vestibulocerebellum, evolved in conjunction with the vestibular system of the inner ear and is mainly responsible for gravitational orientation in higher vertebrates. The vestibular division of the inner ear senses changes in the orientation of an animal's head in all three planes and controls the postural reflexes of the head and neck. These vestibular centers also influence the spinal patterns of posture described above. Vestibular connections are made with the flocculonodular lobes and their nuclei, the fastigial nuclei. This system allows integration of vestibular sensations with other sensory information which passes to the cerebellum from the spinal cord.

The evolutionary changes of the corpus cerebelli in land vertebrates resulted in a new mode of locomotion. The limbs were used to support an animal off the ground and for locomotion as well. It became essential for a land vertebrate to maintain posture and to know the position of its limbs in order to move them in an organized manner.

Mammals

Information on the position of the limbs, and on the state of tonus in the muscles of limbs, is transmitted to the cerebellum via the posterior cerebellar peduncle (**Fig. 3**). The cerebellum does not initiate movement in mammals; it only times the length of muscle contractions and orders the sequence in which muscles should contract to bring about a movement. The command to initiate a movement is received from the cerebral cortex via the middle cerebellar peduncle (**Fig. 3**). Similarly, the cerebral cortex receives information regarding limb position and state of muscular contraction to ensure that its commands can be carried out by the cerebellum.



When the cerebellum receives a command from the cerebral cortex, it transmits a pattern of impulses to the spinal patterns via the dentate nucleus and lower pathways. This pattern of impulses contains the sequence of muscles to be contracted and the length of time of these contractions. At the same time, this same information is transmitted from the cerebellum to the cerebral cortex via the anterior cerebellar peduncle (**Fig. 3**). The cerebral cortex can thus compare its command with the cerebellum's action. This information is then compared with new information coming to the cerebral cortex about changes in

the limbs as a result of the initial movement. If the movement was not adequate, the cerebral cortex can then issue a corrected command to the cerebellum for a new series of movements.

Birds

A similar system for control of locomotion is apparently present in birds. However, the exact nature of the command center, or centers, in the telencephalon is not understood. Birds possess a middle cerebellar peduncle, but the tracts from the telencephalon may not originate in the same areas as in mammals. Birds have a cortical command center, but whether it is homologous with the neocortex of mammals is not known.

Reptiles

Knowledge of the reptilian cerebellar patterns is more fragmentary than those of birds. Reptiles possess a pathway, the dorsal forebrain bundle, from the telencephalon to the cerebellum (**Fig. 4**). This pathway may be homologous, in part, with the middle cerebellar peduncle. The telencephalic center from which this pathway originates is similarly organized in both reptiles and birds. Reptiles possess an interior cerebellar peduncle, but a homologous pathway similar to the mammalian component projecting to the cortex has not been identified. It appears that reptiles, birds, and mammals possess cerebellar patterns of a similar nature. There are differences in organization, but they appear to be secondary and may reflect the added role of the tectum as a second higher center in reptiles and birds.

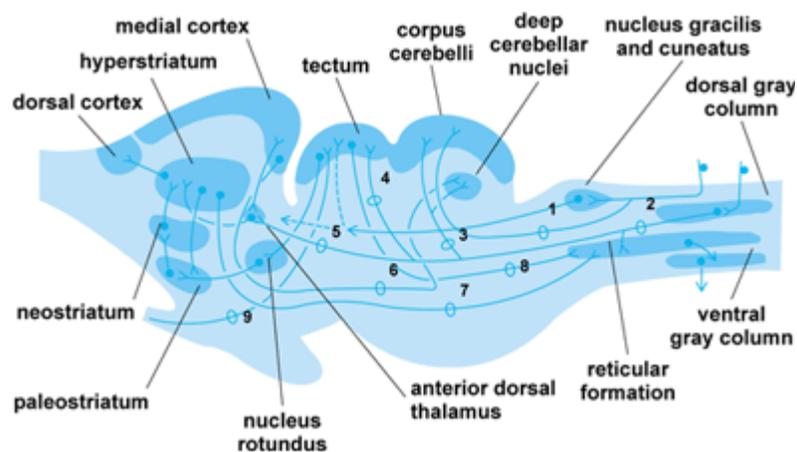


Fig. 4 Reptilian brain in sagittal section illustrating tectal patterns: tract 1, dorsal spinocerebellar tract; 2, lateral funiculus; 3, ventral spinocerebellar tract; 4, spinomesencephalic tract; 5, spinothalamic tract; 6, dorsal forebrain bundle; 7, ventral forebrain bundle; 8, tectospinal tract; and 9, optic tract.

Amphibians

The cerebellum in amphibians is not highly developed. It is divided into the same divisions as in higher vertebrates, and its histology is identical. The locomotor pattern in amphibians is very different from that of other vertebrates, and it is improbable that it functions in the same manner. Salamanders do not use the limbs for support as do higher vertebrates, and frogs have undergone great specialization for jumping. There is little information on the role of the cerebellum in these forms.

Fishes

The cerebellum, particularly the corpus cerebelli, in sharks and bony fish is large. Part of the size is due to the huge number of gustatory fibers projecting to the corpus cerebelli. Both groups of fish possess anterior and posterior cerebellar peduncles. The connections of the anterior cerebellar peduncle are not understood. In bony fish, the tectum is expansive and forms a complex cortex. Tectocerebellar connections are large, indicating that a tectal control center probably exists analogous to the cerebral control center in mammals. Similar tectocerebellar connections exist in other vertebrates, but they do not exist as a

highly developed complex.

Tectal patterns

The mesencephalon is divided into a roof or optic tectum and a floor or tegmentum. The tegmentum contains the nuclei of the oculomotor and trochlear cranial nerves and a rostral continuation of the sensory nucleus of the trigeminal cranial nerve. Two motor nuclei dominate the tegmentum, the ruber nucleus and the substantia nigra. These nuclei are elements in both the telencephalic and the cerebellar motor systems. All of these nuclei are recognizable in most vertebrates. The tegmentum also contains sensory and motor pathways which project between the prosencephalon and lower brain and spinal centers.

The roof of the mesencephalon in lower vertebrates is usually referred to as the optic tectum. Early anatomists realized that the major connections of the optic nerve formed in this area and that this area represented the major center for analysis of visual information. However, in lower vertebrates the optic tectum is also a major center for analysis of somatic sensory information and contains a highly structured center for control of somatic musculature.

The external shape of the tectum has changed greatly in the course of evolution (**Fig. 1**). In fish, amphibians, and reptiles, it forms the roof of the mesencephalon and remains in a dorsal position. In all of these forms, it is normally seen as a paired swelling between the telencephalon and the cerebellum. In birds, each lobe of the tectum has shifted ventrally, and the telencephalon and cerebellum have expanded until they meet along the dorsal surface. In mammals, the tectum has retained its primitive position but is not a large structure. The telencephalon covers its anterior surface, and the cerebellum, its posterior surface; thus it is often not visible from the surface.

In all vertebrates the tectum is divided into two functional regions, an anterior optically dominated region and a posterior dominated auditory region. These divisions may or may not be reflected in the surface structure of the tectum. In mammals, the tectum receives visual information from a division of the optic tract, but the majority of the optic fibers project to the cerebral cortex of the telencephalon after synapsing in a diencephalic nucleus, the lateral geniculate body. This nucleus exists in lower vertebrates and receives optic fibers, as in mammals, but their number is smaller, and the rostral projections, if any, are not known.

A similar condition exists in the auditory pathways. In all vertebrates except mammals, the primary auditory pathway projects to the posterior division of the tectum. In lower vertebrates, this division is called the torus semicircularis. In mammals, some auditory projections occur in the posterior region of the tectum, but the majority of the fibers project to the cerebral cortex of the telencephalon via a diencephalic nucleus, the medial geniculate body.

The tectal pattern in reptiles illustrates the basic connections which occur in all lower vertebrates (**Fig. 4**). The exact functions of these tectal patterns in reptiles and birds have not been discovered. In these two groups, where the telencephalon is also highly developed, the interactions between telencephalon and tectum appear to be very complex.

Diencephalic patterns

In the evolution of vertebrates, the prosencephalon develops as two major divisions, the diencephalon and the telencephalon. The diencephalon retains the tubular form and serves as a relay and integrating center for information passing to and from the telencephalon and lower centers. The telencephalon is divided into a pair of cerebral hemispheres and an unpaired telencephalon medium.

There are three divisions of the diencephalon in all vertebrates: an epithalamus which forms the roof of the neural tube, a thalamus which forms the walls of the neural tube, and a hypothalamus which forms the floor of the neural tube. The

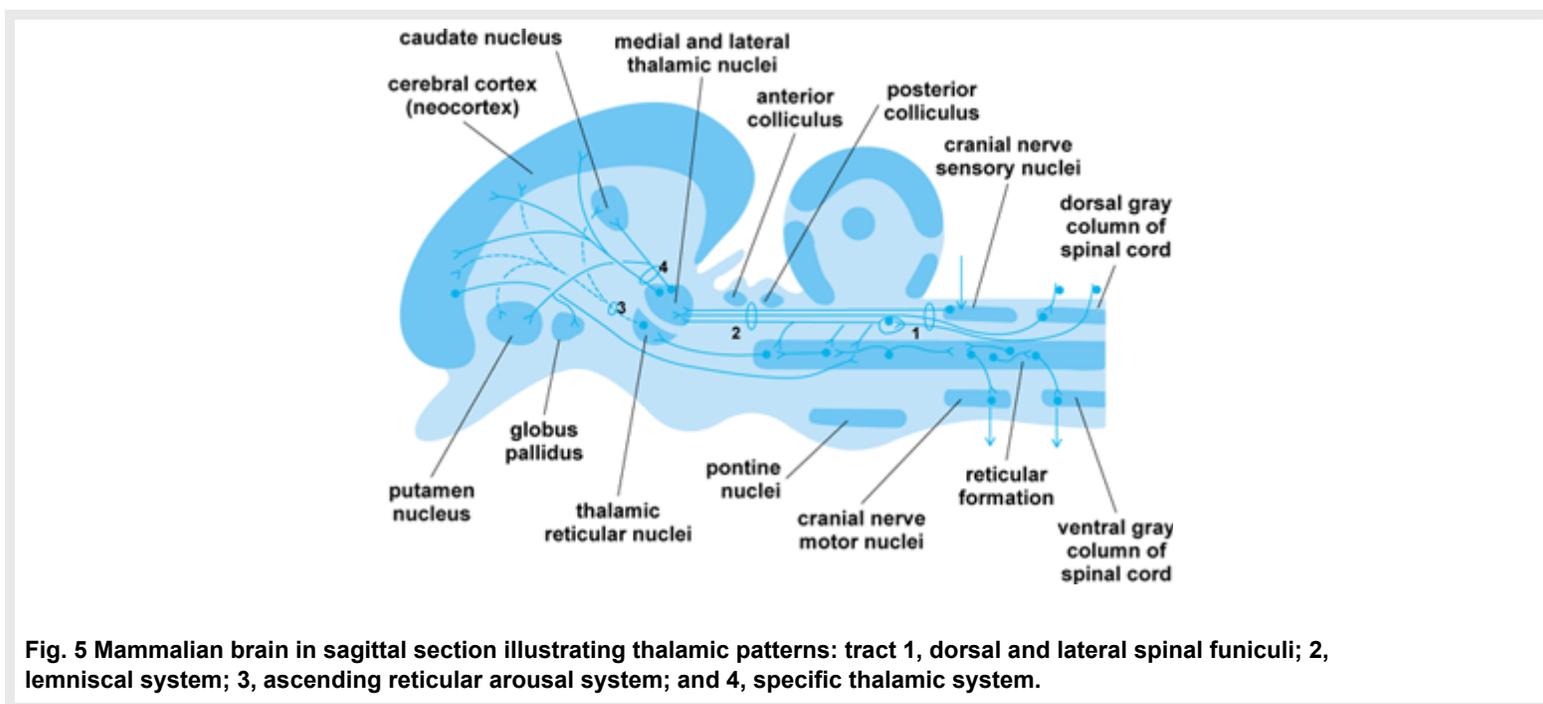
epithalamus and hypothalamus are primarily concerned with autonomic functions such as homeostasis. See also:

[Homeostasis \(/content/homeostasis/321400\)](/content/homeostasis/321400); **[Instinctive behavior \(/content/instinctive-behavior/346700\)](/content/instinctive-behavior/346700)**

In many vertebrates the epithalamus develops two outpocketings from its roof. These are the pineal and parietal processes. The pineal process usually forms a gland with endocrine functions. The parietal process may form an endocrine gland or an eye. In some living reptiles, the parietal eye is highly developed. It apparently was common in many fossil groups as well. See also: **[Endocrine system \(vertebrate\) \(/content/endocrine-system-vertebrate/231900\)](/content/endocrine-system-vertebrate/231900)**; **[Pineal gland \(/content/pineal-gland/518000\)](/content/pineal-gland/518000)**

The thalamus is subdivided into dorsal and ventral regions. The dorsal region relays and integrates sensory information, and the ventral thalamus relays and integrates motor information. In amphibians, the dorsal thalamus is represented by a single group of neurons. In reptiles and birds, this group of neurons has been broken up into a series of nuclei having little, if any, relationship to nuclei found in the thalamus of mammals. Bony fish have a well-developed dorsal thalamus with many nuclei which have been homologized with those of other lower vertebrates, but their functions are unknown.

The dorsal thalamus in higher vertebrates has evolved along two different lines. In reptiles and birds, the dorsal thalamus receives some sensory connections from the spinal cord, but the majority of its connections are with the tectum. In these forms the dorsal thalamus is primarily a relay and integrating center between the tectum and the telencephalon (**Fig. 4**). In mammals, the dorsal thalamus receives connections from the tectum, but the majority of its connections are with the spinal cord and the telencephalon (**Fig. 5**). Thus the dorsal thalamus is a relay and integrating center for sensory information passing from the spinal cord to the telencephalon. Two types of sensory systems project to the telencephalon. The ascending reticular arousal system (**Fig. 5**) passes to the telencephalon and alerts the cortical fields which analyze sensory information. A second system, the specific sensory, or lemniscal, system passes to the sensory cortex and carries specific information on the nature of the stimulus and the position of its origin on the body or head.



Telencephalic patterns

The telencephalon is the most complex brain division in vertebrates. It is divided into a roof, or pallium, and a floor, or basal region. The pallium is divided into three primary divisions (**Fig. 6**): a medial PI or hippocampal division, a dorsal PII or general pallial division, and a lateral PII division, often called the pyriform pallium. The basal region is divided into three areas, the first

of which is a medial BIII area called the septum. A ventral BII area and a lateral BI area form a region often called the corpus striatum.

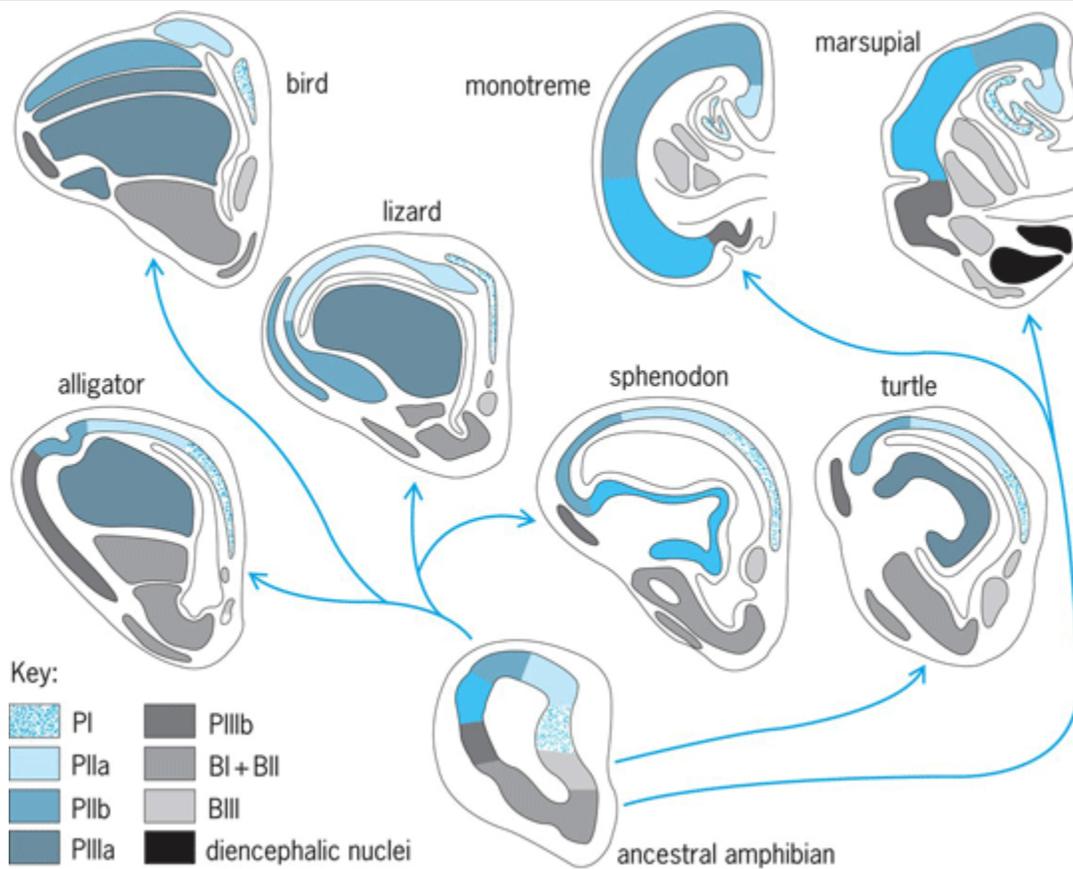


Fig. 6 Cross sections of the right telencephalic hemisphere of several vertebrates, showing evolutionary relationships. Homologous regions of the pallium and corpus striatum are similarly coded.

The most striking change in the telencephalon of land vertebrates involves the PIIIa component, often called the dorsal ventricular ridge (**Fig. 6**). In reptiles and birds, this region has proliferated into the ventricle of the telencephalon to produce a large cellular mass. In mammals, it has proliferated with the PIIb component of the dorsal pallium to produce the mammalian neocortex. In all land vertebrates except amphibians, the PIIb and the PIIIa components, along with the corpus striatum (BI and BII), are the highest centers for the analysis of sensory information and motor coordination. The PI, PIIa, PIIIb, BIII, and posterior parts of BI and BII form part of the limbic system which is concerned with behavioral regulation.

Older theories stated that the telencephalon first possessed only olfactory fibers and that sensory fibers from the thalamus occurred later in evolution, which resulted in the formation of a neocortex. It is now believed that thalamic fibers occur in the PIIIa component of most vertebrates and that all of the vertebrates possess structures of PIIIa origin even though all these structures are not recognized as a neocortex.

Bony fish possess a pallium and a basal region in the telencephalon, but these are organized along different lines than in other vertebrates. Thus the same divisions cannot be recognized.

Cortical representation

The development of a cortex appears to be the most common way in which analyzing and integrating units can be put together in a limited space to produce maximal efficiency. This is reflected in the fact that all three brain divisions have evolved cortices along one or more evolutionary lines. Each evolutionary line has not relied to the same extent on a particular

type of sensory information or its utilization. However, each line has developed cortical surfaces which are specialized for different functions. For example, in mammals the posterior division of the cerebral cortex is concerned with visual impulses, and part of the lateral cortex is concerned with auditory impulses. Anterior to these regions are zones concerned with general sensory and motor impulses.

R. Glenn Northcutt

Comparative Histology

The vertebrate nervous system is composed of nervous tissue, which is one of the four primary tissues of the body. The basic microscopic anatomy of this tissue is essentially similar in all vertebrates although variations do exist. Nervous tissue has the quality of irritability. It is also characterized by the quality of conductivity, to convey the resulting excitation to other structures of the nervous system. The functional roles of nervous tissue include the capabilities to sense, through specialized receptors, environmental energies both internal and external to the organism; to conduct the resulting nerve impulses as coded input to centers in the nervous system; to process this input within these centers; to generate sensations and psychological expressions; and to produce such active responses as the contraction of muscles or the secretions of glands. In effect, nervous tissue reacts to environmental stimuli and regulates many bodily processes so as to maintain functional integrity of an organism. It is within the morphological, physiological, and chemical matrices of nervous tissue that the substrates for memory, behavior, and personality reside. See *also*: [Learning mechanisms \(/content/learning-mechanisms/374910\)](#); [Memory \(/content/memory/414300\)](#); [Personality theory \(/content/personality-theory/501000\)](#)

Structural elements

The nervous system is composed of several basic cell types, including nerve cells called neurons, interstitial cells called neurolemma (cells of Schwann), satellite cells, oligodendroglia, and astroglia; and several connective-tissue cell types, including fibroblasts and microglia, blood vessels, and extracellular fluids.

Neuron

Each neuron possesses three fundamental properties, involving specialized capacity to react to stimuli, to transmit the resulting excitation rapidly to other portions of the cell, and to influence other neurons, muscle, or glandular cells. Each neuron consists of a cell body (soma), one to several cytoplasmic processes called dendrites, and one process called an axon.

Cell bodies vary from about 7 to more than 70 micrometers in diameter; each contains a nucleus and several cytoplasmic structures, including Nissl (chromophil) granules, mitochondria, and neurofibrils. The cell body is continuously synthesizing new cytoplasm, especially protein, which flows down the cell processes. The Nissl granules, found in dendrites as well as in the cell body, are rich in ribonucleoprotein and are responsible for synthesis of proteins for the neuron.

The mitochondria, found throughout the neuron, are the power plants involved in numerous chemical reactions within the cell. The neurofibrils are fine filaments found in living neurons; they are not directly related to conduction of the nerve impulse. The neuroplasm is the structureless ground substance of the cytoplasm in which are found high concentrations of potassium ions and other substrates critical to conduction of impulses and to cellular metabolism.

The dendrites range from a fraction of a millimeter to a few millimeters in length. An axon may range from about a millimeter up to many feet in length.

A most significant structure of the neuron is its cell membrane that acts as a sievelike barrier between the neuronal

cytoplasm, which is negatively charged, and the extracellular fluid, which is positively charged. The functional integrity of the cell membrane and the difference in the bioelectric potential across this membrane are crucial to the physiology of the nerve impulse.

The site where two neurons come into contact with each other and where influences of one neuron are transmitted to the other neuron is called a synapse. A synapse between an axon and a cell body is an axosomatic synapse, and that between an axon and a dendrite is called an axodendritic synapse. At each synapse there is a microscopic space, the synaptic cleft, between the two cells about 20 nanometers wide.

The cell membrane of the axon at the synapse is called the presynaptic membrane and that of the cell body or dendrite is called the postsynaptic membrane. The axon contains vesicles in the vicinity of the presynaptic membrane called presynaptic vesicles, which contain precursors of the neurotransmitter chemicals such as acetylcholine. The neurotransmitters are secreted across the presynaptic membrane into the synaptic cleft where they may excite (excitatory synapse) or inhibit (inhibitory synapse) the postsynaptic membrane. Although a nerve fiber may transmit an impulse in either direction (toward or away from the cell body), conduction in a sequence of neurons is unidirectional: The impulse moves toward the cell body through dendrites and away from the cell body through the axon. This direction is established because the presynaptic neuron can stimulate the postsynaptic neuron but the postsynaptic neuron cannot stimulate the presynaptic neuron. In this context, the synapse acts as a one-way valve and thereby establishes the functional polarity of the neuron. The site of contact of a nerve with a muscle, the motor end plate, is actually a synapse between a nerve and a muscle cell. See also: **[Acetylcholine \(/content/acetylcholine/003900\)](#)**; **[Biopotentials and ionic currents \(/content/biopotentials-and-ionic-currents/083900\)](#)**; **[Sensation \(/content/sensation/614600\)](#)**; **[Synaptic transmission \(/content/synaptic-transmission/674100\)](#)**

Interstitial cells

Except at their synapses and endings, the neurons are in intimate contact with the interstitial cells, the neurolemma (Schwann) cells and satellite cells in the peripheral nervous system, and the astroglia and the oligodendroglia in the central nervous system.

The axon of a peripheral nerve is enveloped by a sequence of neurolemmal cells forming a neurolemmal sheath. In some nerve fibers, the neurolemma elaborates a complex lipid and protein layer called myelin which forms a sheath that is segmented by interruptions at short intervals called nodes of Ranvier. Unmyelinated fibers, nerve fibers without a myelin sheath, conduct nerve impulses at slow velocities, up to about 10 ft/s (3 m/s), while myelinated fibers conduct nerve impulses at speeds of 300–400 ft/s (100–120 m/s). The thicker the myelin sheath the higher is the velocity of the nerve impulse traveling over the nerve. In cold-blooded vertebrates speed of conduction of a myelinated nerve of similar thickness is less than in warm-blooded vertebrates. In the myelinated fiber the impulse hops from one node of Ranvier to the next in what is called saltatory conduction. Satellite cells, variants of neurolemmal cells, envelop the cell bodies of ganglia associated with peripheral nerves. The white matter of the spinal cord and brain contains great numbers of fibers with a myelin sheath, although numerous unmyelinated fibers are found here. The gray matter is composed of unmyelinated fibers, dendrites, and cell bodies.

In the central nervous system, the oligodendroglia serve the same function as neurolemmal cells of the peripheral system; they envelop the cell bodies of neurons and elaborate the myelin sheath surrounding many axons. The astroglia are cells with processes extending between the blood capillaries and the cell bodies of the neurons. In effect they act as intermediaries conveying various products back and forth between the blood and the neurons. The oligodendroglia and the astroglia function to maintain a relatively constant chemical environment to enable the entire neuron to function efficiently.

Connective tissue cells

Nerve fibers of a peripheral nerve are bound together into small bundles by connective tissue cells, fibroblasts, and their fibrous products. The entire nerve is in turn surrounded by more connective tissues, within which are plexuses of blood vessels. Although the connective tissues are sparse within the central nervous system, the blood plexuses of the brain and spinal cord are most extensive. There are three layers of connective tissue membranes, the meninges, covering the brain and spinal cord: the inner, pia mater; the middle layer, the arachnoid; and the outermost, the dura mater. Between the pia mater and the arachnoid is the subarachnoid space; this space and the ventricular cavities within the brain are filled with an extracellular fluid, the cerebrospinal fluid. See also: [Meninges \(/content/meninges/414600\)](/content/meninges/414600)

The microglial cells are the only parenchymal cells of the central nervous system that arise from embryonic mesoderm. These cells are similar to but smaller than macrophages which are derived from connective tissues. During stress conditions, such as inflammatory processes, infection, or traumatic injury to the brain substance, microglia become active and phagocytize and remove breakdown products from the brain and spinal cord.

Functional organization of a neuron

The neuron integrates and processes neural information. The axodendritic and axosomatic synapses stimulate receptor sites on cell membranes of dendrites and cell bodies; these are called the receptive segments. The integrative function of each segment depends, in part, upon the fact that the response to each stimulus from a synapse is graded; it is not an all-or-none nerve impulse. Only after the excitatory and inhibitory synaptic activity of the receptive segment has been resolved into an effective action does the conductile segment, the axon, generate and conduct a nerve impulse on an all-or-none action potential to the next synapse. The region of the axon associated with the synapse is known as the transmissive segment. It is at this site that the neurosecretion is released and transmitted across the synaptic cleft to stimulate the postsynaptic neuron.

Charles Noback

Comparative Embryology

The complicated and varying anatomy of the adult nervous system in different vertebrates makes comparative embryological studies of these structures almost necessary for a sound understanding of their morphology. Few fields in experimental analytical embryology have proved so fruitful as that of neural development. A thorough study of the embryology of the structures under study in animals used for experiments is necessary for a causal analysis. The embryology may be divided into a gross morphogenetic part to analyze the development of the external and internal features of the nervous system, and a histogenetic part to deal with the differentiation of the cells of the nervous system and their arrangement into nuclei and cortical structures.

Nerve growth factor

Neuronal survival, as well as the performance by neurons of some specialized functions, is regulated by macromolecular agents known as neuronotrophic factors. The best studied of these agents, the nerve growth factor (NGF), was discovered in the late 1950s. Nerve growth factor is a protein present in many tissues and biological fluids, but particularly concentrated in some organs. In the organism, neurons might receive nerve growth factor from those cells they innervate, from glial cells with which they are associated, and perhaps also from the general circulation.

The two main cell groups sensitive to nerve growth factor, the dorsal root and the sympathetic ganglionic neurons, belong to the peripheral nervous system, although some central nervous system neurons may also be responsive. During some periods of their development, dorsal root and sympathetic neurons die if nerve growth factor is not present, or if they are treated with

anti-NGF antibody. Beside this critical role for survival, nerve growth factor can also stimulate the neurons to produce neurites (axons and dendrites) as well as some of the enzymes necessary for the synthesis of neurotransmitters. In order to elicit these responses, nerve growth factor must first bind to receptors present on the cell surface. Very few of the molecular events linking this initial binding with the ultimate responses to nerve growth factor, such as neuronal survival or neuritic elongation, are already known.

There is additional evidence for other neuronotrophic factors which regulate survival and performance of different neuronal groups. The search for these factors has been stimulated by information on developmental neuronal death, a widespread phenomenon during development of the nervous system. Of all the neurons in any given population, only those that succeed in making and maintaining synaptic contacts with "target" cells survive. It is believed that each neuron receives from its target cells a neuronotrophic factor which regulates its survival. Neurons that fail to synapse with target cells do not receive the factor, and consequently die. One of the organs whose study has provided support for this hypothesis is the chick embryo ciliary ganglion. A ciliary neuronotrophic factor has been found which is capable of supporting the survival of the neurons from this ganglion. This factor is present in very large amounts in the embryonic eye structures normally innervated by ciliary neurons, at the time of embryonic life when the fate (death versus survival) of these neurons is decided. In addition to this and other neuron-directed survival-promoting factors, other macromolecular agents are under investigation.

Ruben Adler

Formation of neural plate and tube

The anlage of the nervous system is formed in the outer germ layer, the ectoderm, although some later contributions are also obtained from the middle germ layer, the mesoderm. In most vertebrates a neural plate is formed, which later folds into a neural groove, then closes to form a neural tube. In some vertebrate species, such as the lamprey and bony fishes, a massive cord of neural tissue is formed instead, which is later canalized into a neural tube.

In many vertebrates, including chickens and humans, the caudal-most end of the spinal cord is formed by a canalization of a neural cord within the so-called tail bud, while the main part arises as a neural plate.

The formation of neural tissue within the ectoderm is due to inductive influences from underlying chordomesodermal structures. See also: [Developmental biology \(/content/developmental-biology/189300\)](/content/developmental-biology/189300); [Embryonic induction \(/content/embryonic-induction/230200\)](/content/embryonic-induction/230200)

The neural plate curls up at its lateral edges to form a tube (neurulation) in a process which varies somewhat in different vertebrates. The plate has an inherent tendency to form a tube by an active contraction of microfilaments in the apical parts of the cells (close to the future lumen). In some species at least, the surrounding mesoderm apparently partakes in the folding process, pushing the margins of the neural plate (neural folds) upward.

Closing of the neural tube in most species starts in the middle part of the embryonic body, the future neck region, and continues in a rostral and caudal direction. Transitorily a rostral and a caudal neuropore exist.

At the transition between the neural plate and the ectoderm, a thickening, the neural crest, is formed (**Fig. 7**). In the trunk, the ganglia of the spinal nerves are formed from it. In the head, some cells from the neural crest enter mesodermal structures, and others take part in the formation of cranial ganglia. The latter are also formed from ectodermal thickenings lying farther laterally, the placodes. See also: [Neural crest \(/content/neural-crest/449700\)](/content/neural-crest/449700)

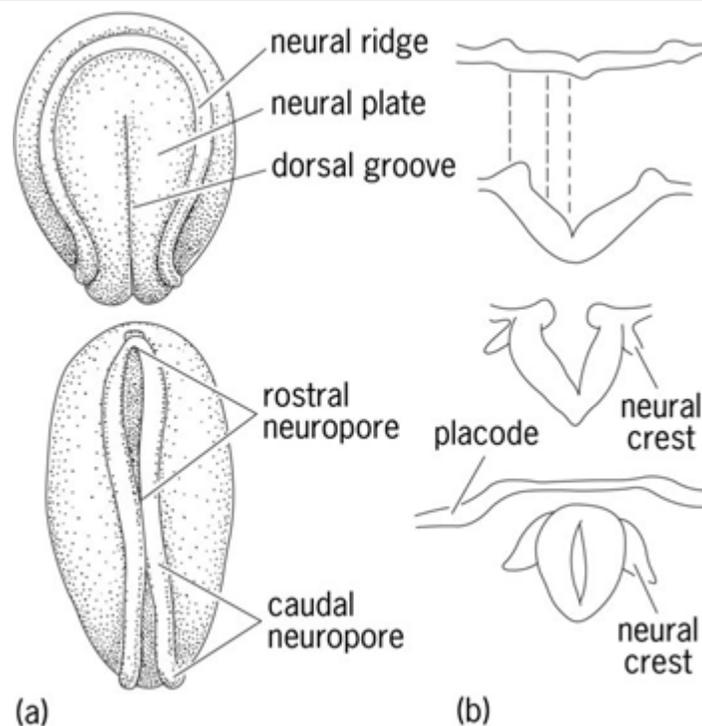


Fig. 7 Transformation of neural plate to a neural tube in amphibians (a) Dorsal views. (b) Transverse sections.

Histologic differentiation

At the site of formation of the neural plate in the ectoderm, the ectodermal cells elongate and form a cylindrical epithelium, the neural epithelium. These cells continue mitotic division and form the primary germinal layer of the central nervous system. At a later stage of development, cells migrate from the epithelium and form a peripheral layer (**Fig. 8**).

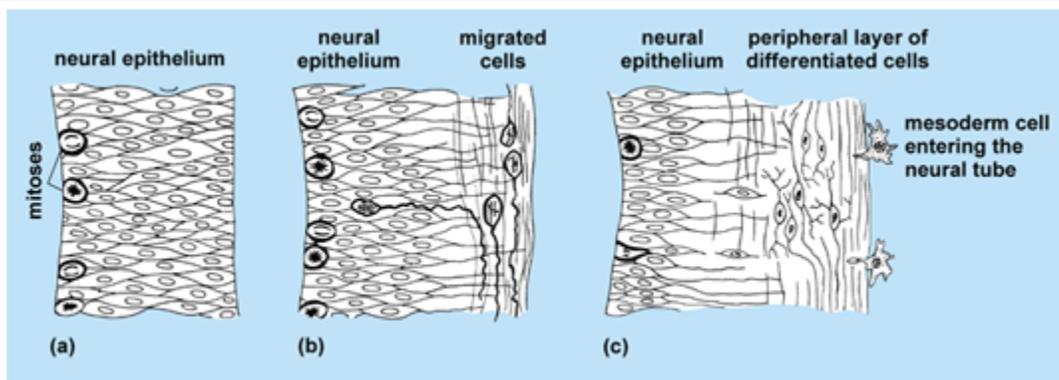


Fig. 8 Cellular constitution of neural tube in different stages a-c; ventricular wall at left.

Within the peripheral layer, and sometimes already within the neural epithelium, the differentiation of the cells proceeds toward neurons and glia cells via neuroblasts and glioblasts, respectively. Also within the ganglia, formed from the neural crest and the placodes, a similar process of differentiation occurs.

From the surrounding mesenchyme (mesoderm), cells enter the central nervous system and form vessels and microglial cells. These cells divide mitotically within the brain substance even in older embryonic stages. Mitotic division of true neural cells outside the neural epithelium is probably of low frequency. In the cerebellum, however, there is a thick proliferating layer of neural epithelial cells which also proliferates peripherally, the so-called embryonic granular layer. Similarly, a proliferating layer exists outside the neural epithelium in the cerebral hemispheres of some mammals, the subependymal layer.

After the formation of neurons and glia cells, the fibers which form give rise to the neuropile of the central nervous system, and to intra- and extracentral nerve bundles. The fibers emanating from the neurons of the ganglia grow as peripheral sensory fibers in peripheral nerves.

Morphogenesis

This aspect includes a consideration of the formation of neuromeres, the longitudinal structuring of the brain, and cell migration. See *also*: **[Morphogenesis \(/content/morphogenesis/035800\)](/content/morphogenesis/035800)**

Neuromeres

When the neural tube is developing, a segmentation of the central nervous system occurs by the formation of transverse bulges, neuromeres (**Fig. 9**). They are most distinctly seen in the hindbrain region, but can usually be identified in suitable embryonic stages in all parts of the central nervous system. They are most easily seen in vertebrate brains having a thin wall, for instance, those of sharks, birds, reptiles, and mammals.

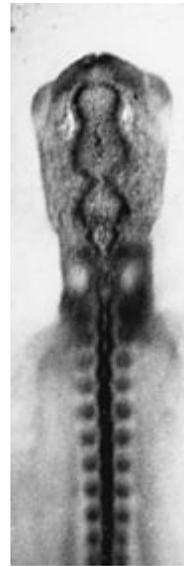


Fig. 9 Photomicrograph, dorsal view, of young chick embryo, showing neuromeres as bulges of the nervous system. (From R. deHaan and H. Ursprung, eds., *Organogenesis*, Holt, Rinehart and Winston, 1965)

Three different sets of neuromeric bulges develop successively, called proneuromeres, neuromeres, and postneuromeres. They represent a primary, secondary, and tertiary segmentation, respectively. The basis of neuromerism is the presence of proliferative patterns. Each set of bulges thus corresponds to one period of increased proliferative activity in the neural epithelium, due to stimulative influences from underlying mesodermal structures. The proneuromeric segmentation extends from the neural tube into the neural crest and causes this to divide in the head region into portions, each corresponding to a proneuromere. This condition results in a topographic correspondence between the cranial ganglia and the neuromeres.

At the time of neuromeric segmentation, the brain is subdivided into the so-called brain vesicles by local widenings of its lumen. In the rostral end, more or less well-developed hemispheres are formed; in the middle of the brain anlage, the mesencephalic bulge develops; and behind the latter the walls of the tube thicken into cerebellar folds. In this way, the brain anlage is divided into five sections: the telencephalon, diencephalon, mesencephalon, metencephalon, and myelencephalon, and its cavity is divided into the rudiments of the adult ventricles (**Fig. 10**). The brain vesicles make the segmental characters of the neuromeric bulges less conspicuous.

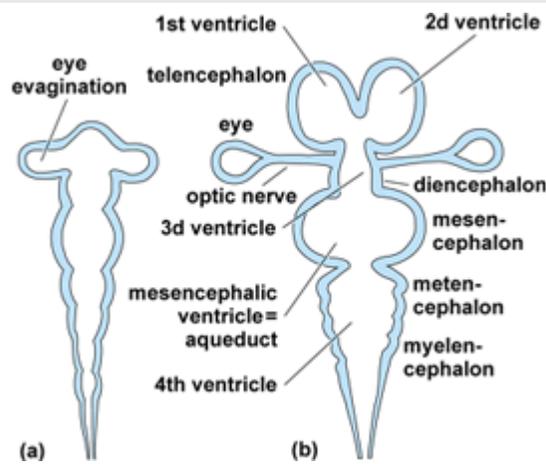


Fig. 10 Schematic horizontal sections through vertebrate brain, showing transformation of (a) neuromeric stage into (b) brain vesicle stage.

When the postneuromeres develop, bulges can be identified only in the brain, not in the spinal cord. The presence of the postneuromeres influences the early development of the internal structures, giving them a slight segmental character.

Longitudinal columns

When the postneuromeric phase is at its height, a longitudinal structuring of the brain wall develops, consisting of four longitudinal bands of high proliferative and migrative activity. In the hindbrain, these four columns approximately correspond to the anlagen of the four columns of functionally different qualities in the adult brain. In the spinal cord, the two dorsal columns fuse into one and the two ventral columns into another. Rostrally, in the brain, the ventralmost columns stop at the rostral end of the mesencephalon and the dorsalmost columns at the transition zone between the mesencephalon and the metencephalon (the isthmic region). The two middle columns build up the rest of the brain, and the borderline between them ends at the optic chiasma. An approximate borderline between the two middle columns in the spinal cord and the myelencephalon is found in a furrow, the so-called limiting furrow of His. It cannot be identified with certainty in the rostral part of the brain.

The postneuromery and the longitudinal banding will give rise to a checkered pattern of proliferation centers. In the rostral part of the brain, the transverse pattern will dominate, the longitudinal one in the caudal part.

Cell migration

Cell migration takes place from the neural epithelium into the peripheral or mantle layer. The presence of transverse and longitudinal proliferation centers will give rise to certain areas which are rich in cells, and will cause a vivid lateral migration. Such areas are called migration areas, and their topography will be determined by postneuromery and longitudinal banding. The number and topography of the migration areas will be very similar in all vertebrate species.

The cells, which have migrated laterally, may still lie in close contact with the neural epithelium and the ventricular wall, as in amphibians, or may lose contact with the epithelium and lie as a peripheral layer (**Fig. 11**). In many species, especially higher vertebrates, successive migrations of cells occur, giving rise to two or more layers of such cells, situated concentrically. This feature is especially well marked in the cerebral hemispheres.

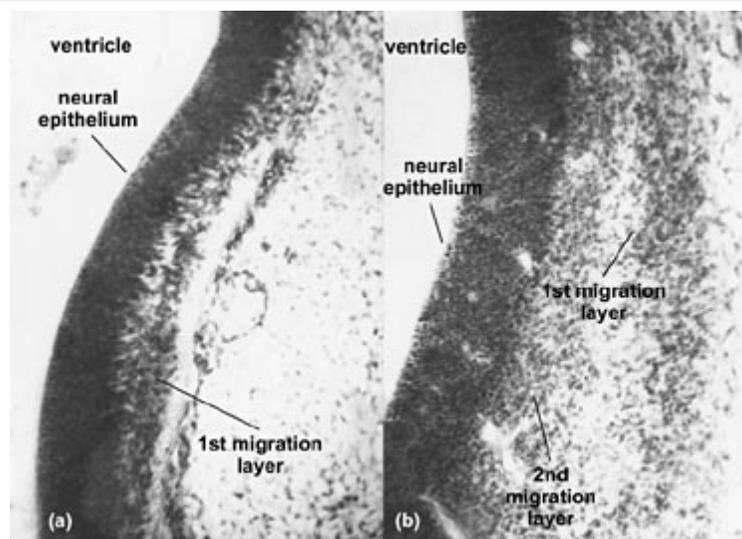


Fig. 11 Two sections through a chick embryonic hemisphere, showing the neural epithelium and the cells migrating from it. (a) One thin migration layer exists. (b) Two migration layers lie outside each other.

Later in development, cells can migrate right through the primarily migrated cell layers—for example, the most external cortical layers can be formed later than more centrally situated cell masses.

The migration layers may fuse or further subdivide into cell clusters, which represent the anlagen of the future brain nuclei. Therefore, they furnish the basis for comparative studies and homologizations of brain nuclei of different vertebrates.

Whole cell groups or brain nuclei may migrate (group migration), and in this way the topography of the nuclei may shift even from one brain vesicle to another. Long-distance migration of scattered neural cells are also known, for example, along the surface of human hemispheres from the basal brain up to the convexities.

Cell death

Within the central nervous system cell death occurs embryonically as part of normal development. Some regions degenerate and are eliminated. This occurs, for instance, below the primary optic stalks, which in this way are shifted to their definite ventral position on the brain. The uneven thickness of the spinal cord motor cell column is also obtained by localized degeneration of neuroblasts. Furthermore, scattered cells die within the nervous system, most markedly in connection with rapid cellular differentiation. Probably, such dying cells are defective and incapable of differentiating. See also: [Cell senescence \(/content/cell-senescence/117250\)](/content/cell-senescence/117250)

Orientation of outgrowing neurites

Maturing neuroblasts send out neurites that build up fascicles and tracts connecting various neural centers.

The growth of neurites is guided by mechanical factors to some extent; chemical or electrical forces play no role, at least at a distance. The actual establishment of contacts between growing neurites and their correct target cells may be determined by cytoaffinity, that is, similarities in the properties of the cell surface.

Brain

In spite of the extraordinary variation in adult morphology of the vertebrate brain in different species, the early phases of development are essentially similar. The brain vesicle stages of a reptile, bird, and mammal are much alike, but owing to varying growth rates of different parts and to specialization processes the different patterns of the adult brains are formed

(Fig. 12).

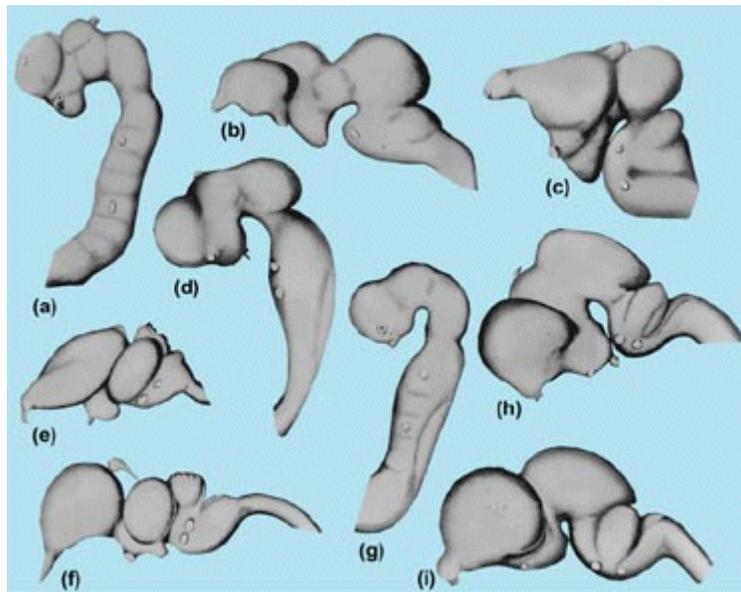


Fig. 12 Lateral views of embryonic brain at progressive stages of development. The early phases are essentially similar. (a–c) Reptile (*Chelydra*). (d–f) Bird (*Melopsittacus*). (g–i) Mammal (*Spermophilus*).

In a comparison of the embryology of the brains of anamniotes and those of amniotes a marked difference is seen in the so-called brain flexures. The originally straight brain tube is bent during development. In a shark or amphibian embryo the only marked bending is the cephalic flexure, situated in the same plane as the mesencephalon. This is also the first to develop in amniotes. In these brains, however, a nuchal flexure is also formed at the transition between brain and spinal cord anlagen, and later a pontine flexure arises ventral to the cerebellar region (Fig. 13). The flexures are most easily seen in median sections.

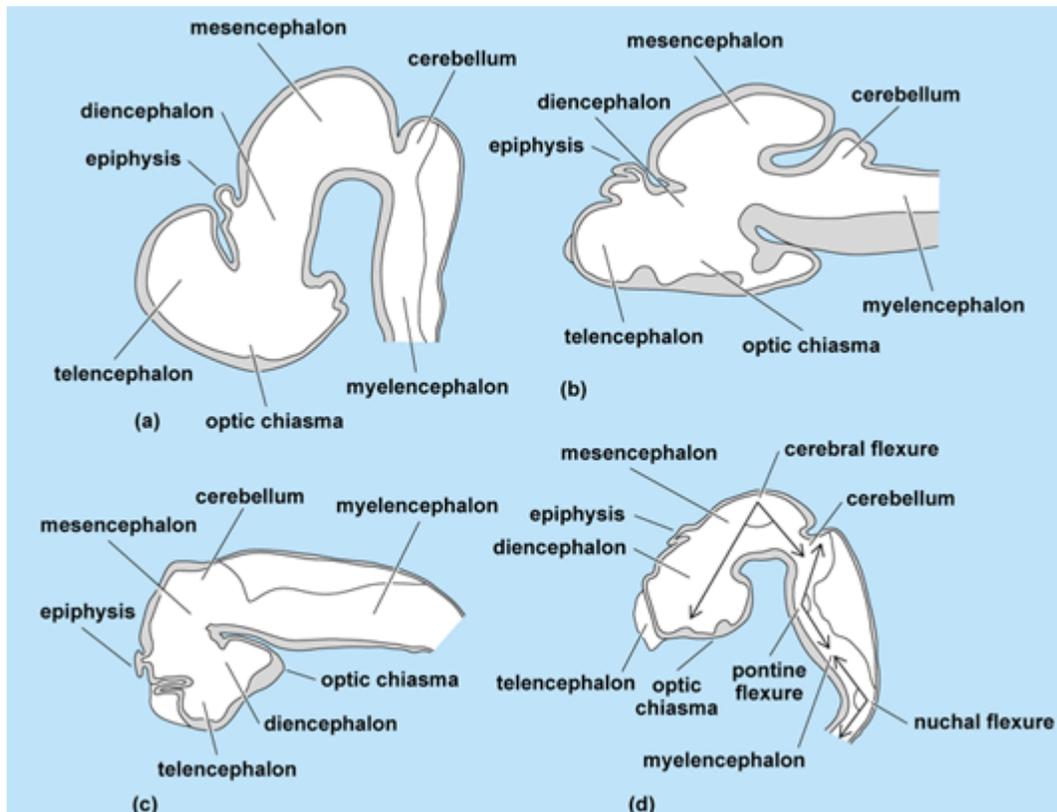
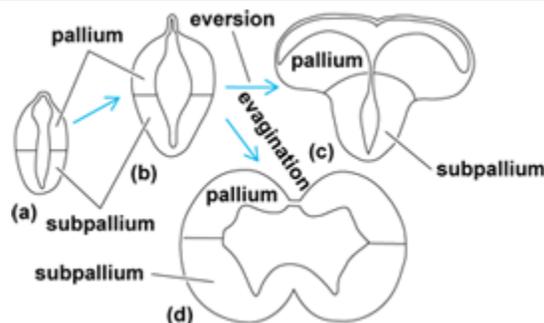


Fig. 13 Median sections of the brains of embryos. (a) Shark. (b) Bony fish. (c) Salamander. (d) Reptile.

Telencephalon

The morphogenesis of the telencephalon of most vertebrates occurs by a lateral evagination or outbulging of the wall, giving rise to two hemispheric vesicles. In bony fishes, ganoids, and holocephalians, however, the lateral evagination is only faintly marked. Instead, a lateral bending, or eversion, occurs. The topography of the internal structures in the two kinds of forebrain will therefore be different (**Fig. 14**).

**Fig. 14 Schemes showing transverse sections of forebrains. (a) Primitive stage develops via (b) interstage to (c) eversion or (d) evagination.**

In all vertebrates two migration areas develop in the telencephalon—a dorsal one representing the embryonic origin of the pallium, and a ventral one representing the subpallium. Each of these areas is further subdivided into cell columns from which the different mantle regions and the septal and striatal nuclei develop.

Diencephalon

The morphogenesis of the diencephalon varies little in different species. A more or less well-developed transverse velum is formed in the roof, caudal to which the epiphyseal rudiment is situated. The paraphysis, which is included in the telencephalon, lies rostral to it. Part of the hypophysis develops from the bottom of the diencephalon while from the ventrolateral parts of the diencephalon the eyes are formed. The lateral walls are divided into a dorsal thalamic and a ventral hypothalamic region, containing the mammillary bodies. The hypothalamic region grows more in size in lower vertebrates than the thalamic does, while in higher vertebrates the opposite condition exists.

Mesencephalon

The original single mesencephalic vesicle is divided into two vesicles which communicate broadly with each other. In lower vertebrates, this condition remains unchanged. The original wide ventricular cavity in higher forms is reduced to form the mammalian Sylvian aqueduct. The evaginations are connected ventrally with an unevaginated part, the tegmentum. Within the latter, the tegmental nuclei, oculomotor nuclei, and the red and black nuclei (nucleus ruber and nucleus niger) develop. The mesencephalic evaginations form the bigeminal bodies in lower forms and the quadrigeminal bodies in higher forms.

Metencephalon

The cerebellum is formed in the dorsal part of the metencephalon. Its degree of development in different vertebrates varies considerably. The original raised lateral walls of the brain fuse to form a single plate. This is extremely compact, for example, in the bony fishes, and from its rostral end a so-called valvula grows rostrally. In *Petromyzon*, amphibians, and most reptiles, the cerebellum remains as a simple transverse plate. In sharks, birds, and mammals, it develops into a dome, which may be more or less folded, thereby increasing its surface.

In most vertebrates, a secondary proliferative layer, the embryonic external granular layer, is formed in the periphery of the cerebellum; this layer disappears during later development.

Myelencephalon

This brain part remains relatively primitive. Its roof is extended as a thin tela; its walls form a more or less V-shaped structure with only small variations. The internal structures are dominated in their development by the above-mentioned longitudinal columns.

Spinal cord

The spinal cord remains as a comparatively slightly differentiated tube. The primary lumen is secondarily reduced by the fusion of the side walls into a narrow central canal. In the lateral walls, the longitudinal columns, separated by the limiting furrow of His, develop into the dorsal and ventral horns respectively. In fishes the diameter of the spinal cord tube gradually diminishes in a rostrocaudal direction, but in four-footed animals intumescents develop level with the extremities by a process of partial degeneration of the regions situated in between.

Cranial nerves

The cranial or cerebral nerves are the peripheral nerves of the head that are related to the brain. The number and degree of development of the nerves varies in different species. The functional quality of the different nerves also varies. Twelve pairs of cranial nerves have been distinguished in human anatomy (**Fig. 15**) and these nerves have been numbered rostrally to caudally as follows:

- I. Olfactory nerve, fila olfactoria
- II. Optic nerve, fasciculus opticus
- III. Oculomotor nerve
- IV. Trochlear nerve
- V. Trigeminal nerve, in most vertebrates divided into three branches: ophthalmic, maxillary, and mandibular
- VI. Abducens nerve
- VII. Facial nerve
- VIII. Statoacoustic nerve
- IX. Glossopharyngeal nerve
- X. Vagus nerve
- XI. Accessory nerve
- XII. Hypoglossal nerve

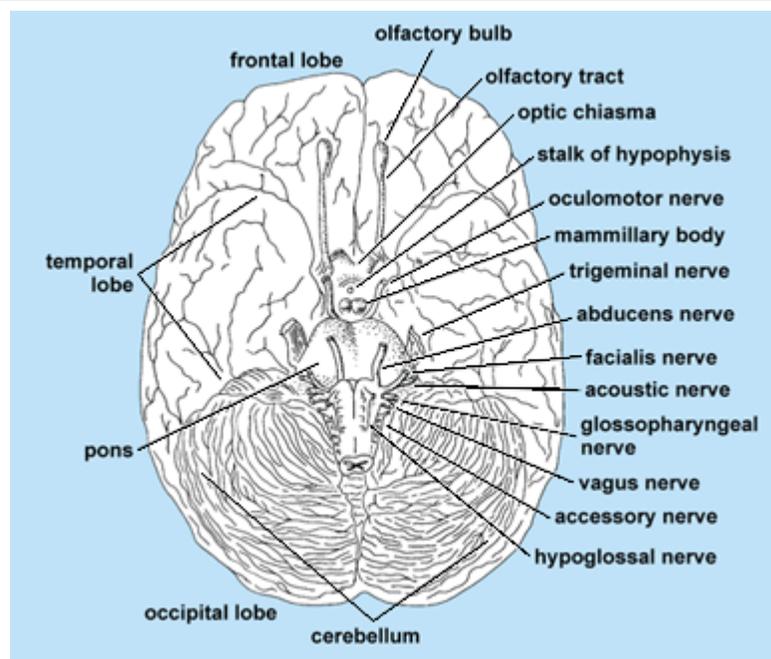


Fig. 15 Drawing of human brain seen from below.

The varied morphological significance of the cranial nerves is evident from their embryology.

Olfactory nerve

Fibers of the olfactory nerve grow out from the primary sensory cells of the epithelium of the nasal sac. They run to the lateral surface of the telencephalic rudiment, usually entering it on the border between the pallial and subpallial regions.

Optic nerve

The eyes develop as evaginations from the lateral walls of the diencephalon. The stalks of the evaginations are the pathways of the future optic nerves. The neurites growing in from the retina within the stalk are comparable to an intracerebral fascicle. They reach the brain in the floor of the diencephalon to form the optic chiasma. See also: [Eye \(vertebrate\) \(/content/eye-vertebrate/249600\)](#)

Ventral motor nerves

Neurites emerge from cells situated in the ventralmost longitudinal column of the brain stem and leave the brain surface as motor nerves. These nerves are the oculomotor, trochlear, abducens, and hypoglossal. The trochlear nerve fibers first grow dorsad, cross in the roof of the brain, and leave it dorsally in the fold between the mesencephalon and the cerebellum. The other nerves leave the brain ventrally. In *Petromyzon*, the trochlear nerve nucleus develops dorsally at the site of the future crossing.

Dorsal nerves

The dorsal nerves (trigeminal, facial, statoacoustic, glossopharyngeal, vagus, and accessory) are all mixed nerves except the statoacoustic. The sensory fibers grow out from neurons differentiated within the cranial ganglia. The motor fibers come from cells lying within the brain stem.

The cranial ganglia are formed from the head portions of the neural crest and from the ectodermal placodes. The neural crest is divided into four or five segments, called the thalamic (present only in lower vertebrates), mesencephalic, trigeminal, facial, and glossopharyngeal-vagus crests.

The placodes of lower vertebrates are made up of two groups, those associated with the lateral-line nerve system and called the dorsolateral placodes, and those situated further ventrally and giving rise to the main ganglia, the ventral placodes. A summary of the vertebrate placodes is given below.

Spinal nerves

The spinal ganglia are formed from the neural crest which grows out like a continuous sheet from the dorsal margin of the neural tube and is secondarily split up into cell groups, the ganglia, by a segmentating influence from the somites. Fibers grow out from the ganglionic cells and form the sensory fibers of the spinal nerves. Motor nerve fibers emerge from cells situated in the ventral horns of the spinal cord. The ventral motor fibers and the dorsal sensory fibers fuse to form a common stem, which is again laterally divided into branches, innervating the corresponding segment of the body.

Autonomic nervous system

The ganglia of the sympathetic nervous system develop ventrolateral to the spinal cord as neural crest derivatives. At first, a continual column of sympathetic nerve cells is formed; it later subdivides into segmental ganglia. The nerve fibers developing from these cells form the gray communicants to the spinal cord and the peripheral sympathetic nerves. The white communicants develop from spinal cord cells. Along the peripheral nerve fibers, cells migrate to form the secondary plexi and ganglia.

The parasympathetic system is made up of preganglionic fibers emanating as general visceromotor fibers from the brain and from the sacral cord segments. Cells migrate to form the peripheral ganglia along them. See *a/so*: **[Autonomic nervous system \(/content/autonomic-nervous-system/065000\)](#)**

Bengt Kallen

Embryology of Sense Organs

Groups of ganglion cells, connected with the brain and spinal cord, send tiny nerve fibers through cablelike nerves to various parts of the body where they pick up many kinds of sensations which keep the living organism in touch with its environment. Therefore, specialized receptor cells and nerve endings must be provided, especially over wide areas for such senses as touch, pressure, pain, temperature, and muscle and tendon sense. Wherever possible in this discussion, the description of development of special senses in vertebrates is illustrated with human examples. See *a/so*: **[Sense organ \(/content/sense-organ/614700\)](#)**

Free nerve endings

Free nerve endings for pain and touch reach the skin as early as the third month in human fetuses. Their terminal branches then increase as the skin rapidly develops hair and nails from the fourth to sixth months (**Fig. 16**). During this time certain terminal nerve fibers slowly become encased with specialized layers of flat cells. Some near the skin, the Meissner corpuscles, receive tactile stimuli. Nerve loops (**Fig. 17a**) near the skin gradually become encapsulated with specialized connective tissue cells (**Fig. 17b**). Others, Pacinian corpuscles (**Fig. 17c**), receive deep pressure sense and consist of more elaborate concentric cell layers, like sheaths of an onion, wrapped around a tiny nerve fiber. They develop in much the same way as tactile organs.

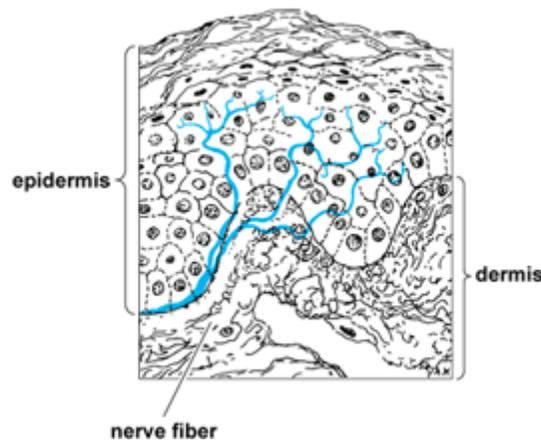


Fig. 16 Schematic of human sensory nerve fiber passing through the dermis and terminating in the free nerve endings among epithelial cells in the skin epidermis.

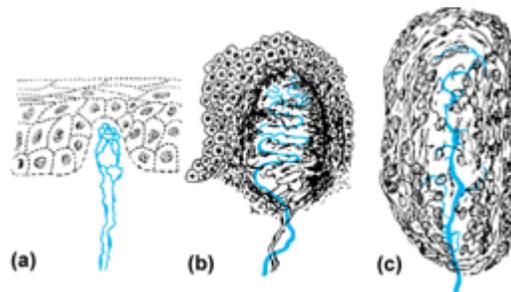


Fig. 17 Human free nerve endings. (a) Nerve loops developing Meissner corpuscle from 7-month human fetus. (b) Adult Meissner corpuscle. (c) Pacinian corpuscle in human fetus at 4 months. (After B. M. Patten, *Human Embryology*, 3d ed., Blakiston-McGraw-Hill, 1968)

Continuing from the third fetal month many sensory nerve fibers spread over the body among developing muscle and tendon fibers, and as they branch, tiny flat plates develop at each nerve ending (**Fig. 18**). A delicate fibrous network of connective tissue finally covers them. The stimuli they pick up and relay to the central nervous system give the awareness of the position of the body and its parts.



Fig. 18 Developing neurotendinous fibers from human fetus of 6 months. (After B. M. Patten, *Human Embryology*, 3d ed., Blakiston-McGraw-Hill, 1968)

Lateral-line organs

Some organs of special sense, such as the eye, are extremely complicated, whereas others are relatively simple. In some aquatic vertebrates (many fishes and amphibians), there are lateral-line skin organs (**Fig. 19**) on the head and body, innervated by nerve trunks coming from cranial ganglion cells connected with the brain. These organs apparently acquaint the animal with pressure changes in the surrounding water giving it a sense of orientation while swimming in a current or a warning of an approaching object. There are no homologs in humans or other animals. These tiny pear-shaped organs

possess several centrally placed, club-shaped sensory cells (**Fig. 19**), each of which ends in a hairlike process at the free surface. These cells are interspersed and surrounded by tall, flat, overlapping, leaflike supporting cells. Fine nerve fibers from the lateral-line nerve (**Fig. 19**) branch among the sensory cells to receive their stimuli. The apex of the organ communicates with a microscopic pore at the skin surface in amphibians, and with a canal system in the skin of fishes.

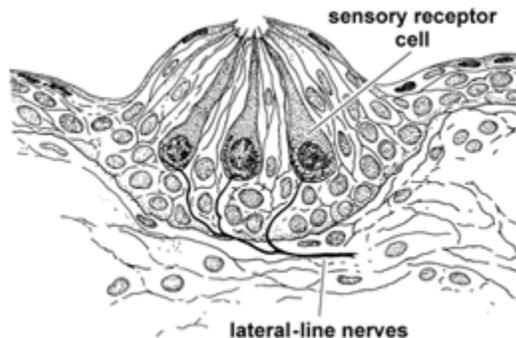


Fig. 19 Schematic drawing of a lateral-line sense organ in skin of adult salamander, the common aquatic vermilion spotted newt. Sensory receptor cells, surrounded by supporting cells and skin epithelium, terminate in hairs projecting into skin pores. Lateral-line nerves terminate around bases of the sensory cells.

In amphibian embryos where they have been extensively studied, ectodermal thickenings, called placodes, first appear on the side of the head. Any one of these placodes can be stained with a blue vital dye (**Fig. 20a**), and as the embryo grows one can follow them as they elongate, migrate on the surface of the head and body (**Fig. 20b** and **c**), and deposit at regular intervals clusters of blue cells that form the lateral-line organs. By this method, one can observe the developing organs under the microscope as the blue-dye particles migrate to the tips of the sensory and supporting cells (**Fig. 21**). Each of them becomes innervated by the lateral-line nerve that follows the migrating placode. This nerve comes from ganglion cells which are also placodal in origin. A cluster of new secondary organs arises by a budding process from supporting cells of the primary organs (**Fig. 22a** and **b**). In practically all frogs and toads, the lateral-line system degenerates at metamorphosis.

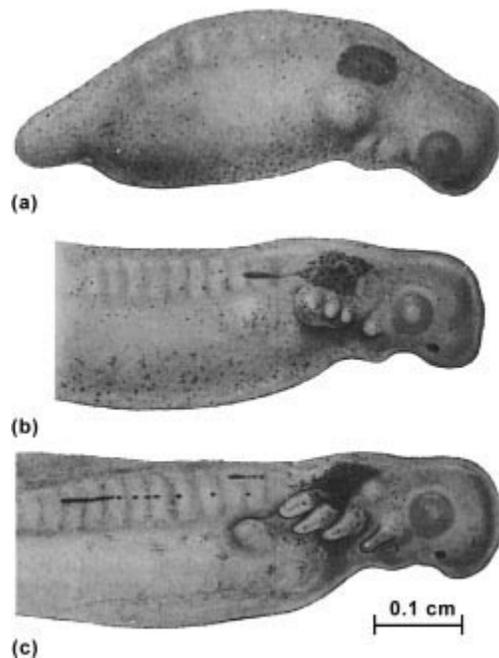


Fig. 20 Lateral-line development in salamander (*Ambystoma punctatum*). (a) Camera-lucida drawing of living embryo made 1 day after a lateral-line placode was excised and replaced by a similar one (shaded) taken from a Nile blue-stained donor. (b) Same living specimen 24 h later, showing one midbody lateral-line primordium migrating in the surface ectoderm toward the tail. (c) Same specimen 24 h later than **b**, showing a long and a shorter lateral-line primordium migrating down side of the body and depositing clusters of blue-stained cells that form the sense organs. (From L. S. Stone, *The development of lateral-line sense organs in amphibians observed in living and vital-stained preparations*, J. Comp.

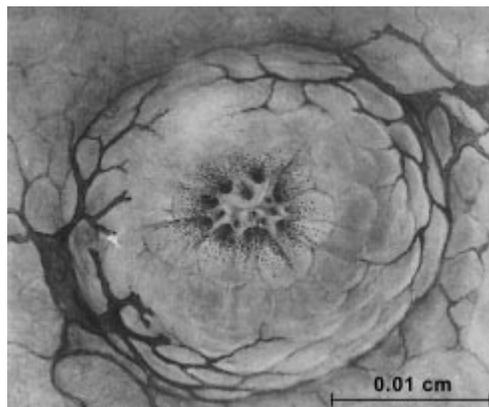


Fig. 21 Camera-lucida drawing of a differentiated living lateral-line organ surrounded by two large pigment cells in skin of young 16.5-mm (0.65 in.) salamander larva, 16 days after operation shown in Fig. 20a. Blue-dye particles were observed during development as they migrated to tips of the central sensory and surrounding supporting cells. (From L. S. Stone, *The development of lateral-line sense organs in amphibians observed in living and vital-stained preparations*, *J. Comp. Neurol.*, 57(3):507-540, 1933)

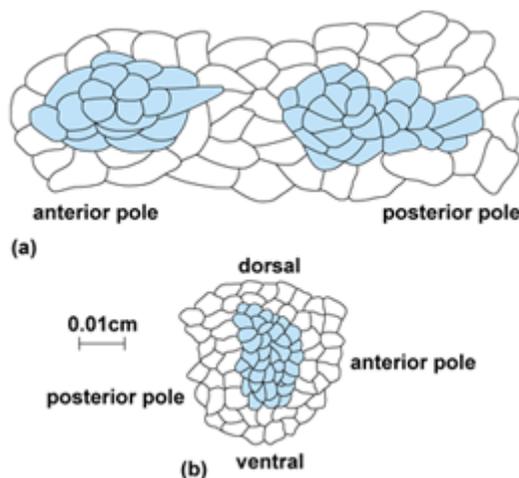


Fig. 22 Camera-lucida drawings of *Ambystoma punctatum* outlining lateral-line organs (shaded cells) in process of budding. (a) Budding organ at posterior pole was derived 24 h earlier from organ at anterior pole in tail of larva. (b) Lateral-line organ budding dorsally was observed to be derived by budding 24 h earlier from the one ventral to it. None of the organs were observed budding anteriorly or posteriorly. (After L. S. Stone, *The development of lateral-line sense organs in amphibians observed in living and vital-stained preparation*, *J. Comp. Neurol.*, 57(3):507-540, 1933)

Taste buds

There are special chemical receptors somewhat like a rosebud in shape, called taste buds ([Fig. 23a](#)), or gustatory organs. They are common to all classes of vertebrates and function in a watery environment. They are associated with parts in the oral cavity, especially on the fungiform and circumvalate papillae in the mammalian tongue, but in some fishes, such as the catfish (*Ameiurus*), many taste buds are also found in the skin on the surface of the head and body. The central, rod-shaped sensory cells of mammals ([Fig. 23a](#)), neuromasts, are embraced by slender, overlapping, flat, supporting cells, the outer ends of which surround a pitlike excavation connected through a pore with the mucous epithelium of the mouth. These neuromasts, which send hairlike processes into the pit, are in contact with a basketlike network of nerve fibers. They pick up the stimuli that are then carried by the nerve fibers to the cranial gustatory ganglia and on into the brain. See [also: Tongue \(/content /tongue/700200\)](#)

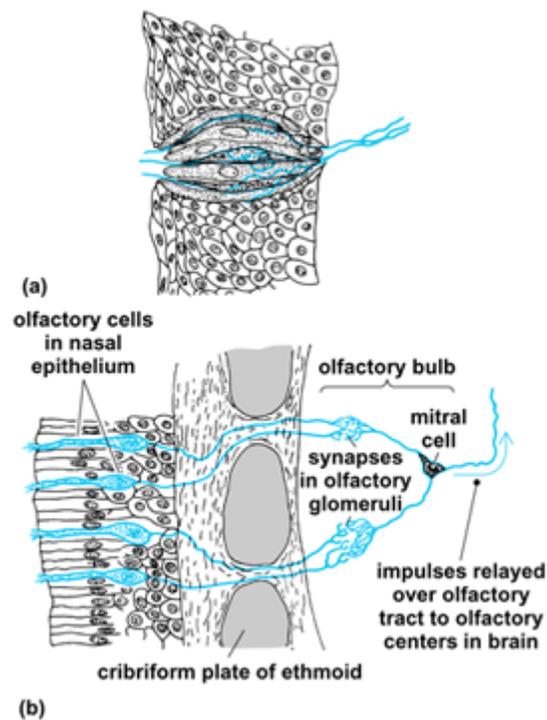


Fig. 23 Mammalian sense organs. (a) Taste bud in lingual epithelium. (b) Olfactory sensory cells of the nose related to nerve tracts leading to the brain. (After B. M. Patten, *Human Embryology*, 3d ed., Blakiston-McGraw-Hill, 1968)

In the tongue of the human fetus, the taste buds first appear as clusters of epithelial cells and increase in number as the gustatory nerve fibers reach the epithelium. Although the taste organs are known to degenerate eventually after gustatory nerves are cut, their arrival at the epithelium in the first place may not be the stimulus which induces the organs to form.

It has been shown conclusively by experiments on salamander embryos that the lining of the floor of the future mouth can be transplanted from one embryo to the side of the body of another embryo; a tongue with taste organs develops later without having been innervated. It was also found that if the epibranchial ectodermal placodes on the sides of the head, which give rise to the gustatory ganglia, are excised, the taste organs develop normally without a nerve supply. How these special sense organs arise in any vertebrate is not known. Taste organs, like lateral-line organs, were found to increase in number by a continuous budding process from the peripheral supporting cells of older taste organs. In many vertebrates, there is a continuous increase in taste buds for a long period. It is quite possible that this is accomplished by a similar budding process. Very little is known about the time at which the taste organs become functional. Some investigators believe that significant reflex responses can be induced in premature 7-month infants by sweet, sour, and bitter tastes.

Olfactory structures

In humans, the sense of smell also depends on special neurosensory epithelial cells functioning in a moist environment within the nasal cavities. The area of specialized olfactory epithelium lies in the upper deeper roof of the nasal mucous membrane and is made up of tall cells with bristlelike processes projecting into the mucus-covered surface where they act as chemical receptors (**Fig. 23b**). They are surrounded by tall supporting cells and extend toward the brain as thin fibers which contact fibers of intermediate ganglion or mitral cells. These in turn relay the olfactory impulses along the olfactory tract to the appropriate centers in the brain.

The olfactory organs arise in a similar manner in all vertebrates, by an early appearance of a pair of surface ectodermal thickenings, nasal placodes (**Fig. 24**), at the front end of the head. Considerable evidence from experiments on amphibian embryos indicates that the formation of nasal placodes can be induced by neighboring mesoderm and brain-forming cells.

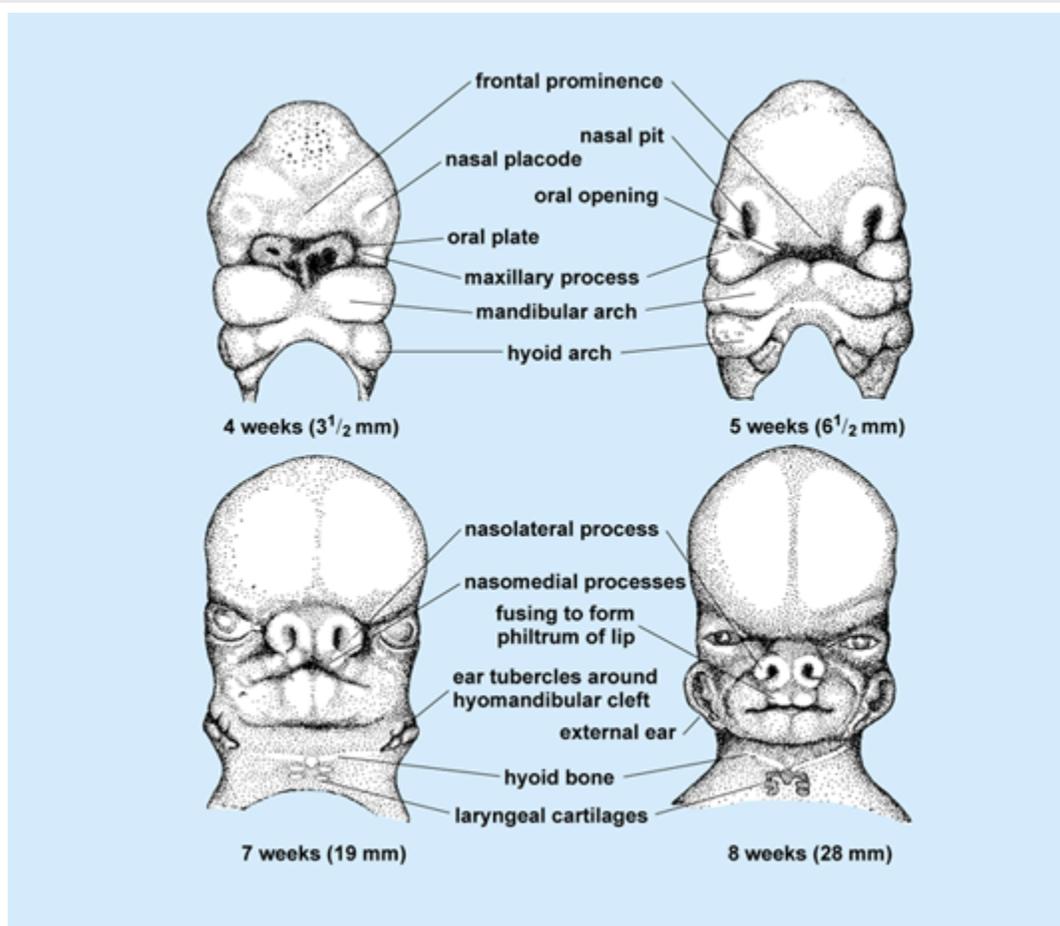


Fig. 24 Development of nose and other facial features in human embryos. (After B. M. Patten, *Human Embryology*, 3d ed., Blakiston–McGraw-Hill, 1968)

In human embryos, the nasal placodes appear during the fourth week. Very soon the placodes sink inward, forming pits which become deeper as the frame of the nose and surrounding structures of the face rapidly develop. The nasal cavities extend deeply and downward toward the oral cavity, with which they communicate shortly after the seventh week. The forward growth of the palate, nose, upper lip, and median nasal septum aids in formation of the nasal passages during the second month. By this time in the roof of the two nasal passages, specialized sensory cells of the olfactory epithelium are surrounded by tall supporting cells.

Except for the skinlike lining at the entrance of the nares, all other areas of the nasal cavities become covered by columnar epithelium with surface cilia and mucus-secreting cells. These cells keep the entire membrane covered with a moist film that provides the environment later for chemical stimulus of the hairlike ends of the sensory cells. The rate at which full differentiation of this sensory mechanism takes place varies among the vertebrates. The normality of the framework of the nose as well as the face and head depends a great deal upon the ability of the mesoderm to reach its full development.

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