5 / NERVOUS SYSTEM.

Introduction. The nervous system is the most important organisation which controls and integrates the different bodily functions and likewise maintains a stability or constancy of the internal environment despite extreme changes in the external environment. The activities of the nervous system depends upon a complex interplay of numerous dynamic interactions or regulatory reactions. This system is absolutely necessary for the reception, storage and release of different sensory and motor informations for regulating or initiating a particular behaviour of the individual ranging from the cellular to the gross animal being the unique feature of nervous system is that unlike any other systems, the nervous system can inhibit or modify any sensory signal so any unimportant sensory impulse can be ignored without responding to it. It is a very complicated system ; structures and organs are specialised for different specific purposes.

The nervous system operates through two main system : (*a*) the *central or somatic nervous system, and* (*b*) the *autonomic nervous system* which again consists of the *sympathetic and parasympathetic systems.* The nervous system is ectodermal in origin.

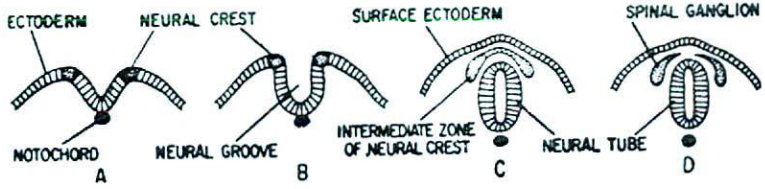


FIG. 5.1. Diagram showing the transverse sections through successively older embryos. Cells of the neural crest, initially forming an intermediate zone between the neural tube and surface ectoderm in C and later form spinal and cranial ganglia.

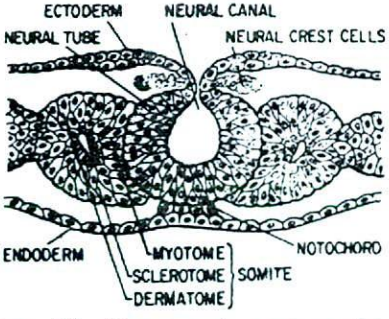


FIG. 5.2. Diagrammatic representation of the cross-section through the dorsal aspect of the embryo.

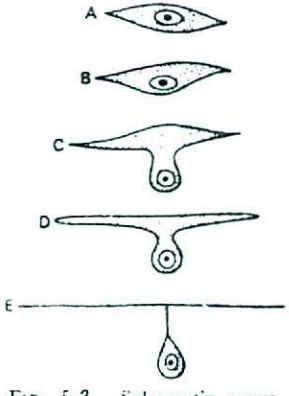


FIG. 5.3. Schematic representation of the successively embryological development of a sensory nerve fibre

Development. The nervous system develops from the primitive layer of cells — ectoderm and also develops from the neural plate or medullary plate which, on further differntiation, gives rise to median neural groove limited on each side by neural folds fusing with each other into neural tube. The cephalic

tube develops into brain and its ventricle, whereas the caudal end gives rise to the spinal cord and its central canal. The sympathetic chain arises from the neural crest (FIGS. 5.1 & 5.2). The nerve cells are derived from the **neuroblasts,** while the neuroglia from the **spongioblasts** (chiefly).

Histogenesis of nerve tissue (FIGS. 5.3 & 5.4). The germinal cells are differentiated from the outer part of the columnar or nuclear layer and then further differentiated along two different lines: (*i*) *neural cells*—**neuroblasts** and (*ii*) *glial cells*—**spongioblasts.**

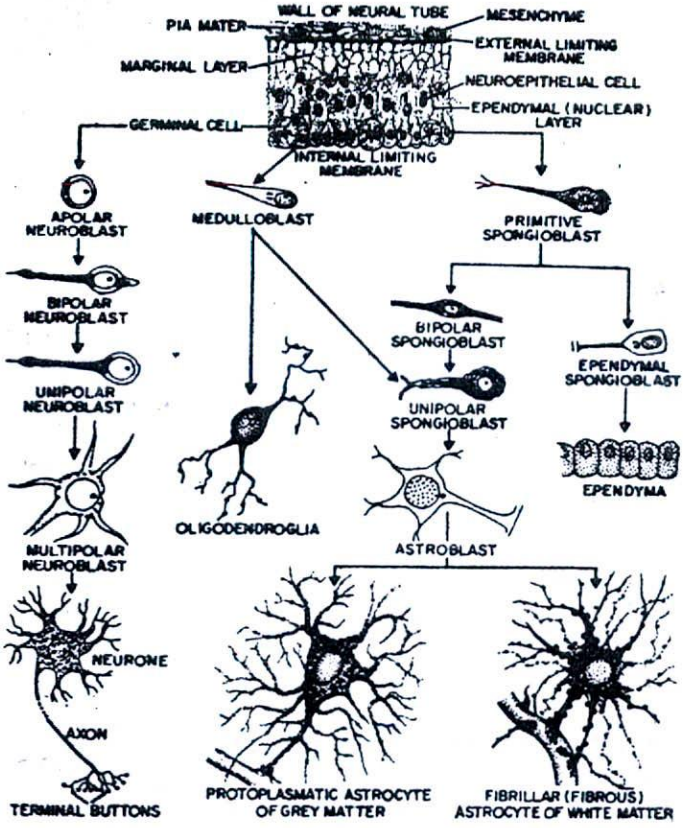


FIG. 5.4. Diagrammatic representation of histogenesis of the nervous tissue.

Neural cells. The neuroblasts, passing through different stages, ultimately give rise the matured neurone. *First*, the neurofibrils appear in the cytoplasm of the neuroblast (*apolar*) and the cells gradually migrate from the central canal to which it remains attached by a process. The *apolar neuroblast* sends out a process towards the periphery, the axon (*bipolar*). Now the bipolar neuroblast looses its attachment to the central canal and so named as the unipolar neuroblast. Dendrites appear at the end of the above stage and on completion the *multipolar neuroblasts or neurones* are matured.

Glial cells (Spongioblasts). The *primary* (*primitive*) *spongioblasts* are differentiated into *astroblasts* after attaining the *bipolar* and *unipolar* stages. The astroblasts acquire connection with blood through the protoplasmic extensions, the *end feet*. They are further branched enormously to form the *protoplasmic astrocyte*. In some astroblasts, after branching, glial fibrils appear in the cytoplasm and form *fibrillar* (*fibrous*) *astrocytes* which possibly consist of α-keratin.

The primitive spongioblasts are also differentiated as *ependymal spongioblasts* and ultimately the *ependymal cells* are formed.

The *medulloblasts* (undifferentiated) may, by proliferation and differentiation, produce *spongioblasts* (unipolar), *neuroblasts* (apolar) and *oligodendroglia*.

The aforesaid classifications can be represented in Fig. 5.4.

The whole nervous system can be divided into two main systems:

1. *Central nervous system.* 2. *Peripheral nervous system.*

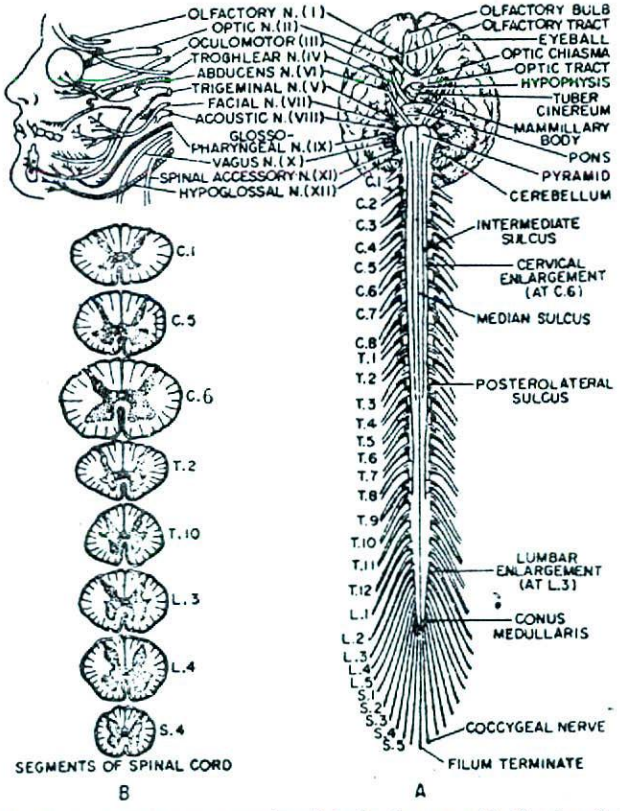
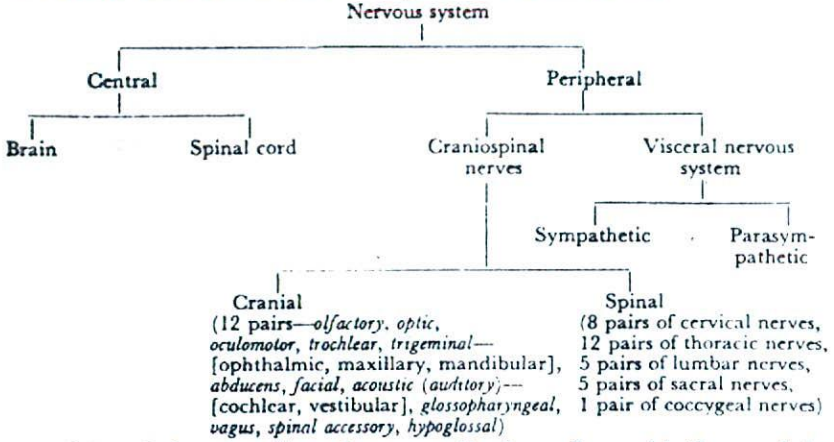


Fig. 5.5. Diagrammatic representation of the brain stem with 12 pairs of attached cranial nerves; spinal cord with 8 pairs of cervical nerves, 12 pairs of thoracic nerves, 5 pairs of lumbar nerves, 5 pairs of sacral nerves and 1 pair of coccygeal nerves in A. Some spinal cord segments at different levels varying in shape, size and topography of gray and white matter with *letters* and *numbers* of the corresponding segments in B.

The *central nervous system* consists of brain and spinal cord, whereas the *peripheral nervous system* consists of (*i*) *craniospinal nerves* having 12 pairs of cranial nerves and 31 pairs of spinal nerves (FIG. 5.5 A), (*ii*) *visceral nervous system* comprising *sympathetic nervous system* and *parasympathetic nervous system*. The above subdivisions have been presented schematically.



Although functionally and structurally the surface epithelium and the

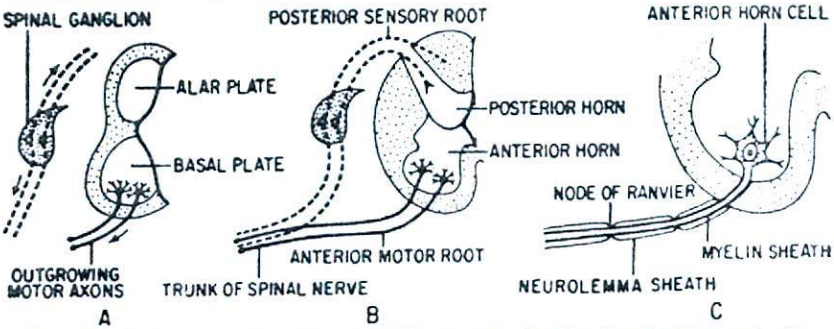


FIG. 5.6. A shows outgoing motor axons of cells in the basal plate and the centrally and peripherally growing fibres of the nerve cells in spinal ganglion. In B, nerve fibres of the ventral motor and dorsal sensory roots join to form the trunk of the spinal nerve. In C, diagram shows an anterior horn cell and its axon surrounded by neurolemma and myelin sheath.

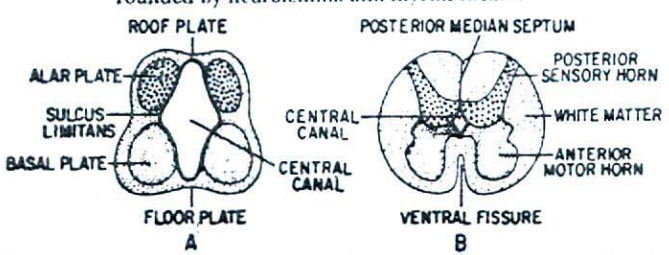


FIG. 5.7. **Diagrammatic** representation of two successive stages in the development of **the spinal cord** showing the formation of anterior and posterior horns, etc.

nerve cells have departed a long way from each other, yet the fact stands that they are the offspring of the same parent—the ectoderm.

Central or Somatic nervous system. The central or somatic nervous system (FIGS. 5.6 & 5.8) is symmetrically arranged into two lateral halves—one-half being the mirror image of the other. It consists broadly of: (1) **spinal cord**—inside the vertebral column, and (2) **brain**—inside the cranial cavity—skull. The *foramen magnum* is the limiting line.

Spinal cord

Spinal cord being surrounded by its covering lies loosely within the vertebral column and is extended from the foramen magnum as far down as the interspace between the 12th thoracic segment and the lower border of the 1st lumbar vertebra. During early development (FIG. 5.7), the spinal cord is extended up to the lower end of the sacrum, but with the further development and mostly at fourth month of development, the vertebral column is elongated more rapidly than the spinal cord. Due to inproportionate development of the cord and the vertebral column, the spinal cord, being anchored to the medulla oblongata, is pulled upward in the spinal canal and causing its caudal end to reach the lower border of the first lumbar spines in the adult (FIG. 5.9). There is some variation in individual to individual and it is slightly lower in women.

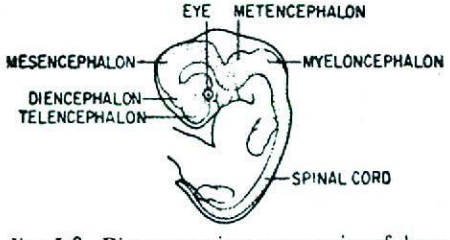


FIG. 5.8. Diagrammatic representation of development of the nervous system, showing the neural tube in stipple. Note the expansion at the cranial end and constrictions demarcating subdivisions of the brain.

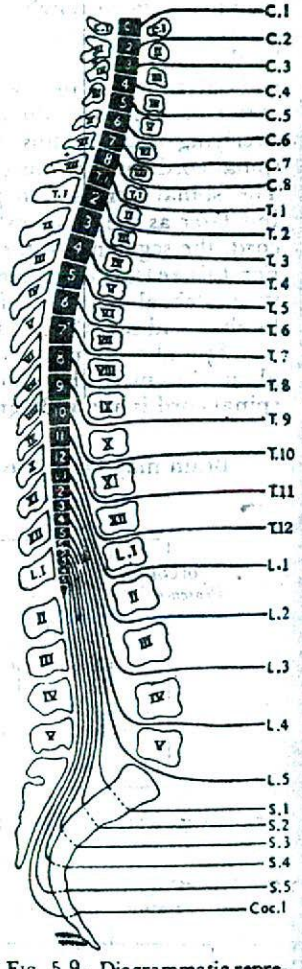


FIG. 5.9. Diagrammatic representation of the segments of the spinal cord with reference to the bodies and spinous processes of the vertebrae (*after Haymaker and Woodhall*).

The spinal cord is mostly cylindrical in shape and is flattened anteroposteriorly. It has got two swelling, one in cervical-6 and other in lumbar-3 of the spinal cord (FIG. 5.5B).

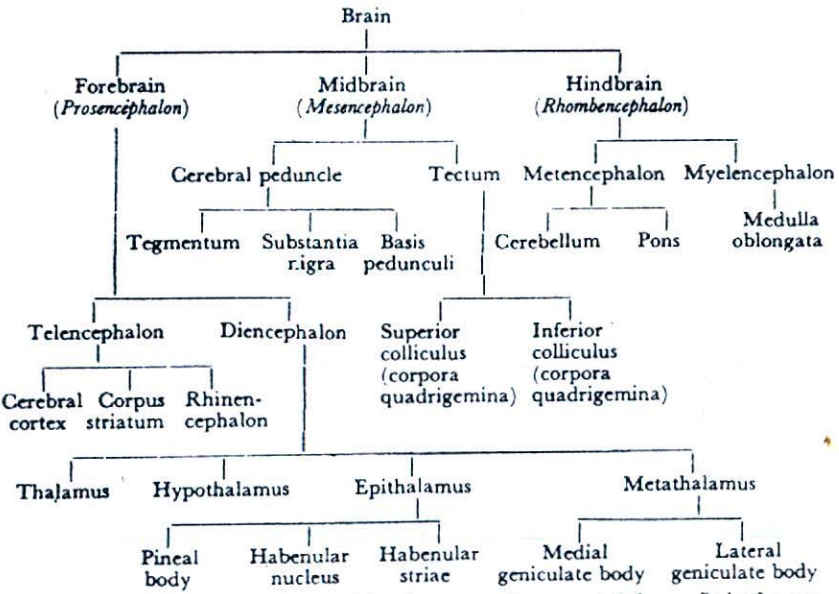
Physiologically, the spinal cord is regarded as made up of a series of superimposed segments, from each of which a pair of nerve roots arise.

Intrinsically the spinal cord is a continuous and unsegmented structure with 31 pairs of nerves emerging from it. Each segment of the spinal cord gives rise to dorsal and ventral root filaments. Dorsal and ventral roots together form a single pair of nerves. 31 segments of the spinal cord correspond to 8 pairs of cervical and 12 pairs of thoracic, 5 pairs of lumbar and 5 pairs of sacral and 1 pair of coccygeal nerves. As the cord ends at the level of lower border of the 1st lumbar vertebra, spinal segments evidently do not correspond numerically with the vertebrae overlying them. Thus during early development, each segment of the spinal cord corresponds closely with the respective embryonic vertebrae. The spinal nerves also pass at laterally to their intervertebral foramina. But later as the vertebral column develops more rapidly than the spinal cord, the segments of the latter do not correspond the respective vertebra. For this reason the interval between the spinal origin of the nerve and its vertebral exit is different from segment to segment. Hence the lumbar and sacral nerves have long roots (FIG. 5.9).

Spinal cord from its upper limit to the tip of the conus medullaris is about 45 cm in the male and 43 cm in the female. The weight of the spinal cord is about 35 gm.

Brain

Brain may be subdivided (FIGS. 5.10 & 5.11) as follows:



1. **Medulla.** It is situated in the posterior cranial fossa. It is the upward continuation of the cervical spinal cord extending from the foramen magnum to the caudal border of the pons. It is the centre for the autonomic reflex control of the circulation, heart and lungs. It is also the integrated autonomic reflex centre for swallowing, coughing, sneezing, gagging and vomiting (*vide* later).

2. **Pons.** It is situated in front and above the medulla, with various

nuclei and tracts. It appears anteriorly as a bulging mass of transverse fibres and is separated from the cerebellum posteriorly by the IVth ventricle. Furthermore, the external feature of the pons is the broad band of

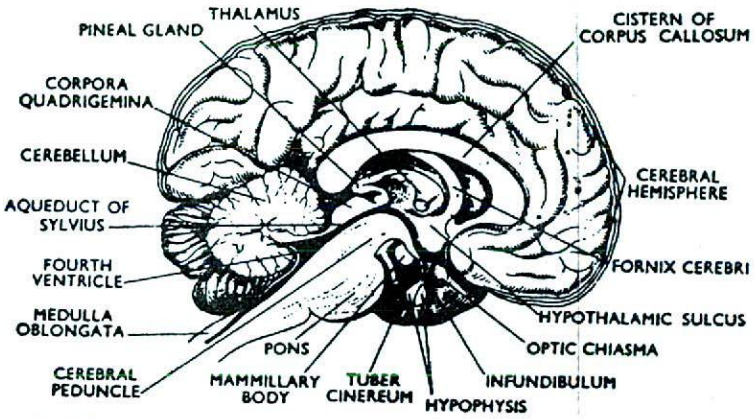


FIG. 5.10. Diagrammatic representation of median sagittal section of the brain stem.

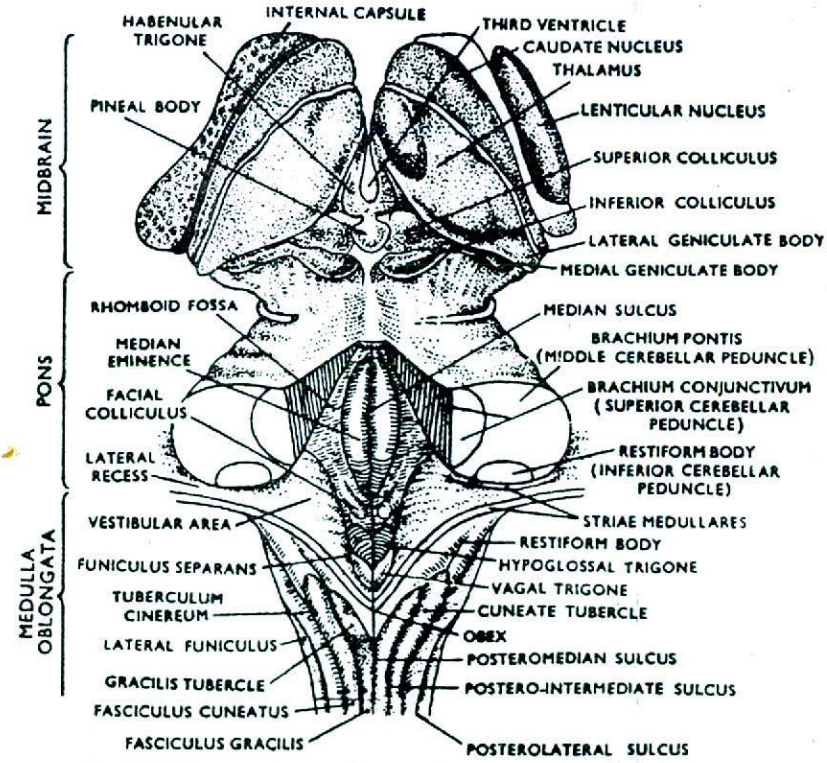


FIG. 5.11. Diagram showing the posterior view of the human brain stem.

predominantly transverse fibres. It is demarcated from the cerebral peduncles of the midbrain by the superior pontine sulcus and from anterior surface of the medulla by the inferior pontine sulcus.

The pons takes part in regulation of respiration and also other important vital regulations.

3. **Cerebellum.** Above and behind the medulla and attached to the central nervous system by three peduncles: *superior*, *middle* and *inferior*. The cerebellum is concerned with the co-ordination and adjustment of smooth movement. It is thus related with posture. Degree and extent of movement (volitional) is determined by cerebellar feedback control (*vide* later).

4. **Midbrain.** It is the upward continuation of the brain stem. Through it passes the *aqueduct of Sylvius*. Dorsal to the aqueduct (*tectum*) are present certain collections of the nerve cells, viz., *superior colliculus*, *inferior colliculus*. Laterally and below the aqueduct lie the *red nucleus* and the *third nerve nucleus*. The part ventral to the aqueduct is called the *cerebral peduncle*. The peduncle is divided into two areas—ventral and dorsal—by a dark line of nerve cells containing melanin called the *substantia nigra*. The ventral area is called the *crusta* or *pes*. The cortical fibres descend through it. The dorsal area is called *tegmentum*. Through it pass all the ascending and some descending fibres, such as the *medial fillet*, the *lateral fillet*, the *ventral and dorsal longitudinal bundles*, the *rubrospinal and tectospinal tracts*, etc.

5. **Geniculate bodies**—*medial* and *lateral*
6. **Cerebrum**
7. **Thalamus**
8. **Basal ganglia**
9. **Hypothalamus**

} discussed in their respective places.

Meninges, ventricles and cerebrospinal fluid. The brain and spinal cord remain covered by three membranes (*meninges*), which from outside inwards are known as—*dura mater*, *arachnoid mater* and *pia mater* (Figs. 5.13 & 5.24). Under the arachnoid there is *subarachnoid space*, containing *cerebrospinal fluid*. The interior of the nervous system is hollowed out

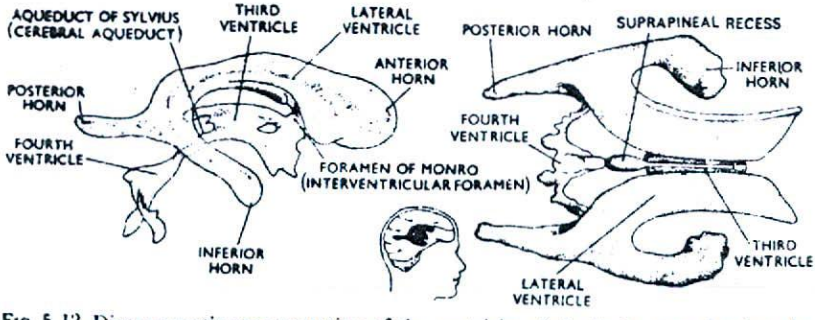


Fig. 5.12. Diagrammatic representation of the ventricles of the brain stem showing the lateral view at the left side and the dorsal view at the right side.

by four cavities (ventricles) and two canals, all filled up with cerebrospinal fluid. One cavity is present in each cerebral hemisphere—called the *lateral ventricle*. They open into a common central cavity—the *third ventricle*, through an opening on each side—the *foramen of Monro* (interventricular foramen). The third ventricle is continued down through the

midbrain as the *aqueduct of Sylvius* (cerebral aqueduct) (Figs.5.12, 5.13 & 5.14). The aqueduct opens into another dilatation in the medulla—the

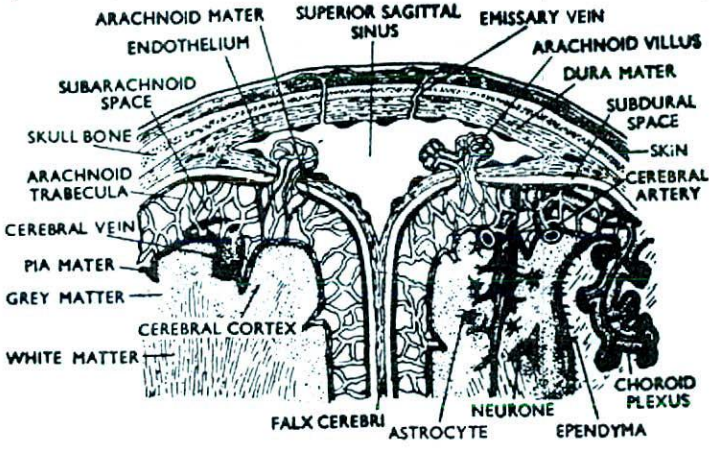


Fig. 5.13. Diagrammatic representation of the coronal section through the vertex of the cranium showing the cerebral meninges, superior sagittal sinus and arachnoid villus in relation to the brain and skull bone.

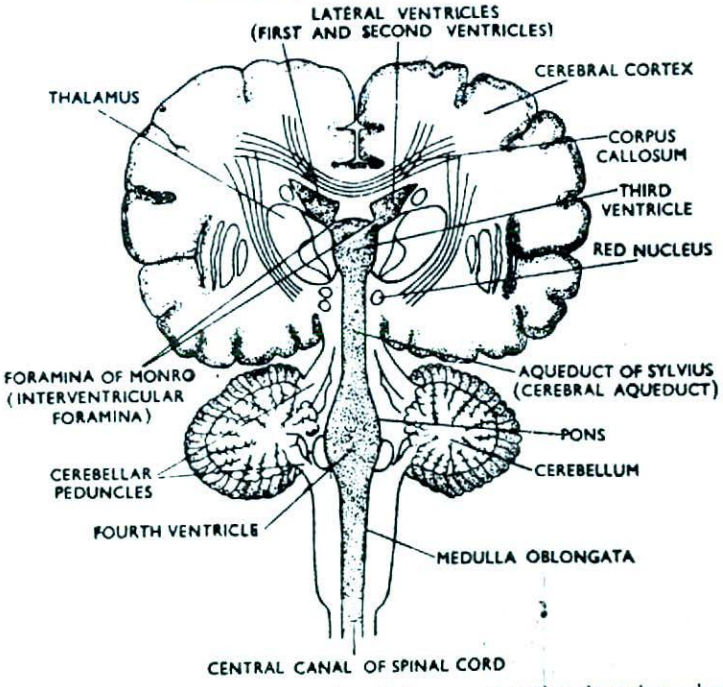


Fig. 5.14. Diagrammatic representation of the coronal section through cerebral hemispheres, brain stem and spinal cord showing approximate relationship of the important parts.

fourth ventricle, which again is continued downwards as the *central canal of the spinal cord*. The roof of the fourth ventricle has three perforations—the central one is called the *foramen of Magendie* ending directly to the cisterna magna, and the two lateral ones—the *foramina of Luschka* ending into the cisterna pontis on the basal aspect of the brain stem. Through these

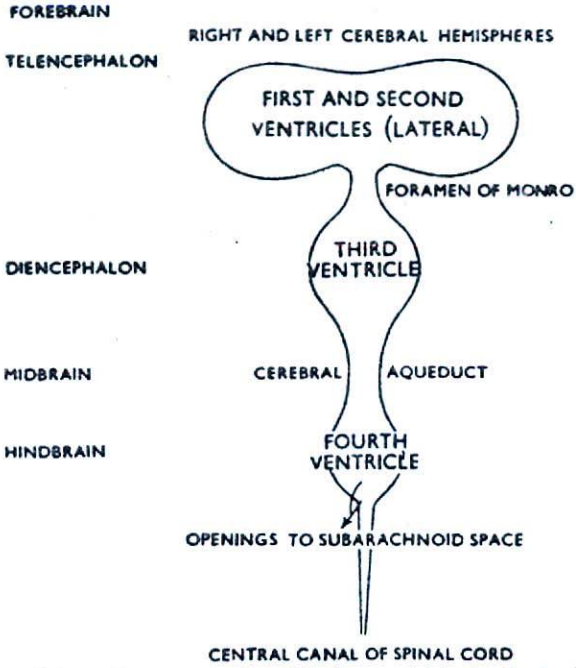


FIG. 5.15. Schematic representation of the four ventricles in the brain stem corresponding to early formation of the forebrain (with specialised developing formation of the telencephalon—forming right and left cerebral hemispheres and the diencephalon), to the midbrain and the hindbrain.

foramina, the cerebrospinal fluid enters the subarachnoid space (FIG. 5.15). Thus the cerebrospinal fluid surrounds the whole central nervous system being both inside and outside it. The ventricles and canals are lined by a *ciliated cubical epithelium*, called the *ependyma*. The movements of the cilia help the circulation of the cerebrospinal fluid.

Blood supply. Very rich—the *average blood flow* of normal subjects in resting condition is 54 ml per 100 gm of brain tissue per minute. Taking the weight of brain as 1400 gm, the total cerebral blood flow is 750 ml or above per minute

Metabolism. (1) O_2 consumption—3·5 ml per 100 gm per minute; (2) respiratory quotient—0·99 per 100 gm per minute; (3) glucose consumption—5·5 mgm per 100 gm per minute; (4) very little store of food or O_2. Hence, easily affected by anoxic, toxic or metabolic derangements.

GENERAL PRINCIPLES OF THE NERVOUS SYSTEM

The following broad facts about the arrangement and working processes of the nervous system will be very helpful for further study.

1. **Divisions of nervous system.** Nervous system has two parts: (*i*) **central or somatic nervous system** (cerebrospinal or voluntary), (*ii*) **autonomic nervous system** (vegetative or involuntary). The latter is generally unconscious and is not under the control of 'will'. It reflexly regulates the activities of the viscera. The former is responsible for consciousness and voluntary control.

2. **Symmetrical arrangement.** The nervous system is arranged symmetrically into two lateral halves. Consequently, except a few, all the centres, tracts, nerves, etc., are bilateral.

3. **Neurone doctrine.** The neurones are the structural and functional units. They communicate with each other directly or indirectly through *synapses*. A synapse is a relay station which transmits the impulse from one neurone to the other.

4. **Principle of peripheral control.** Control of the spinal cord and cerebellum is same-sided (homolateral or ipsilateral), i.e., one lateral half of these structures controls the same half of the body. But the control of cerebrum, thalamus and corpus striatum is mostly opposite-sided (contralateral), i.e., the structures on one side control the opposite half of the body.

5. **Three-neurone arrangements.** From the periphery to the centre there are generally three neurones and two synapses.

6. **Principles of decussation.** *Nerve tracts destined for thalamus and cerebral cortex will cross. Because their control is contralateral. Crossing takes place always in the second neurone. But spinal and cerebellar connections do not cross. Because their control is homolateral.*

7. **Principle of exit and entrance** (Bell-Magendie law). Nerve fibres entering the spinal cord go through the posterior root and nerve fibres emerging from the spinal cord come out through the anterior root.

8. **Seat of consciousness.** Consciousness depends upon the co-ordinated activities of interneurones of the brain.

9. **Varieties of nerve impulses.** Two types of nerve impulses are described: (I) **afferent,** and (II) **efferent.**

I. **Afferent.** These are sensory, centripetal or incoming impulses. They may be either *conscious* or *unconscious*. They are subdivided into three groups:

(*i*) *Exteroceptive*—impulses set up *by stimuli coming from outside*, viz., (*a*) cutaneous senses like touch, pain, temperature, etc., and (*b*) special senses —like vision, hearing, taste and smell.

(*ii*) *Proprioceptive*—kinaesthetic impulses, i.e., those coming from the muscles, tendons, ligaments, joints, etc. The labyrinthine impulses (vestibular) belong to this group. Proprioceptive impulses give information regarding the position of the head and other parts of the body.

(*iii*) *Enteroceptive*—impulses arising from the viscera. They mostly belong to the autonomic system.

II. **Efferent,** outgoing, centrifugal or motor. These again may be of two types: (*a*) *reflex* (*involuntary*), and (*b*) *voluntary* (*motor unit*).

10. **General functions of the nervous system.** Depending on the type of nerve impulse and its interpretation, functions of the nervous system may be of the following three types:

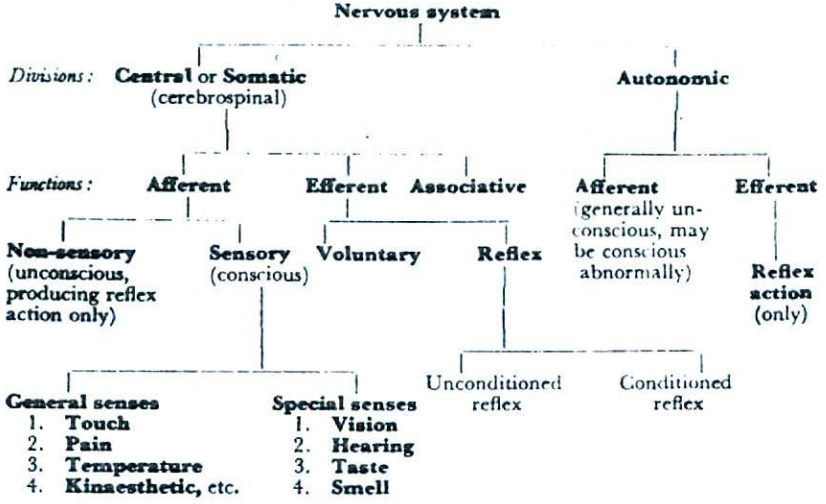
(*i*) **Sensory functions.** These may be either conscious or unconscious. When conscious they are called **sensations.** In the involuntary nervous system they are usually unconscious.

(*ii*) **Motor functions.** These may be of two types: (*a*) **Reflex** or **involuntary.** (*b*) **Voluntary.** In the autonomic nervous system, all motor effects are reflex. In the central or somatic system, both.

(*iii*) **Associative functions.** For instance, idea, memory, intelligence, etc. These are carried out mainly by the cerebrum.

A brief summary of the **functional divisions** of the nervous system is given in the following scheme:

Functional divisions of the nervous system



HISTOLOGICAL STRUCTURE OF THE NERVOUS SYSTEM

The nervous system is composed of **nervous tissue.** The nervous tissue consists of two elements: (1) The nerve cell or **neurone (neuron).** (2) The **neuroglia.**

Neurone

A nerve cell with all its processes is called a neurone (FIG. 5.16). *It is the structural and functional unit of the nervous system.* Neurone may consist of a

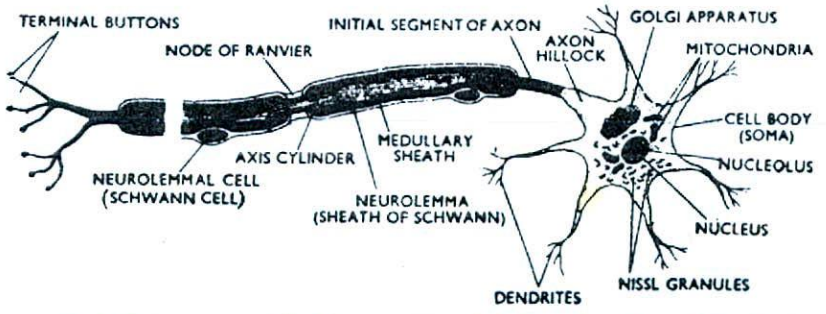


FIG. 5.16. A neurone with all its processes and the formation of a medullated nerve fibre (diagrammatic).

nerve cell body or soma and two types of processes—*axon* and *dendrite* (*dendron*). [For *Structure of Nerve Fibres—vide* pages 66–68.]

Axon. (1) *Axon is the* process of a nerve cell body that carries impulse away from it. Nerve fibres which carry impulses to the central nervous system are termed afferent and those carrying impulses from the central nervous system to the periphery are known as efferent. The term nerve fibres usually refers to the axons. Thus the peripheral mixed nerves containing both sensory and motor fibres are axons (FIG. 5.17). (2) It arises from that part of

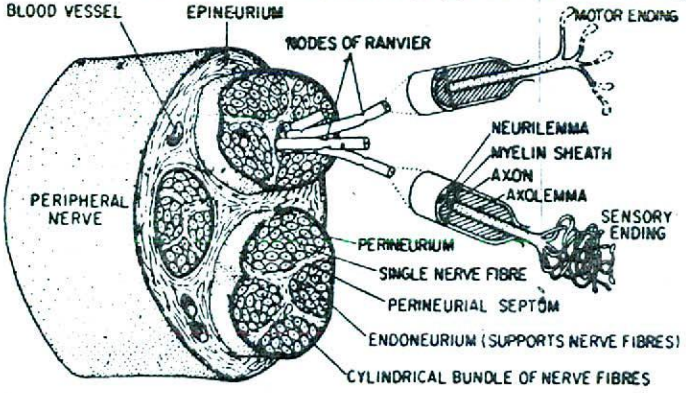


FIG. 5.17. It shows the presence of axon in both sensory and motor fibres of a mixed peripheral nerve trunk.

the nerve cell, called the *axon hillock*. (3) It is generally long with few branches (*collaterals*). (4) It contains no Nissl granules. (5) Axon is single but constant. If a neurone has only one process, it will be the axon. (6) Axis cylinder contains *axoplasm*—a semifluid substance, essential for nutrition and growth of the nerve fibre. (7) It also contains *neurofibrils* and *mitochondria*. (8) Being single and elongated cytoplasmic neuronal extension with the specialised functions of conducting impulses away from the *dendritic zone*, the axon at last ends in numerous *terminal buttons* **(axon telodendria).**

Dendrite or Dendron. (1) *Dendrite or dendron is* the process that carries impulse towards the cell body. It collects impulses from other neurones and carries them towards the cell body. (2) It is generally short with many branches, and (3) contains Nissl granules. (4) Number varies from nil to numerous. (5) Dendrites are, as a rule, multiple, relatively short and follow specific branching pattern. It is presumed that dendrites do not conduct impulse like axons in the central nervous system and instead they are the part of receptor membrane of the neurone.

Cell body (FIGS. 5.18 & 5.19). The *cell body* is called the **neurocyton (soma).** Neurones are commonly classified according to the number of their processes: (*a*) **Apolar neurones** have no process. (*b*) **Unipolar neurones**—All developing neuroblasts pass through a stage when they have only one process—the axon. In the adult human such true unipolar neurones are not commonly seen, but they are found in the mesencephalic nucleus of the 5th cranial nerve. (*c*) **Bipolar neurones**—Typically these neurones are spindle-shaped possessing the axon at one pole and a dendrite at the other. Numerous, developing neuroblasts pass through

this stage. In the adult, they are usually found in the retina, in the vestibular ganglion, in the spiral ganglion of the cochlea, and in the olfactory neuro-epithelium. (*d*) **Pseudounipolar neurones**—Such atypical bipolar neurones are found in all spinal ganglia and in the ganglia of the cranial nerves other than those of 8th cranial nerve. These types of neurones are at first typically bipolar and spindle-shaped, but as development proceeds the cell processes converge until these meet at one side of the cell body. Then this elongates so that a fine process is formed with a T-shaped division at the end, one branch of the T being the dendrite from the periphery and the other being an axon extends centrally. (*e*) **Multipolar neurones**—These neurones have most varied form. A few of the common types are Purkinje cell of the cerebellar cortex, pyramidal cell of the motor cortex,

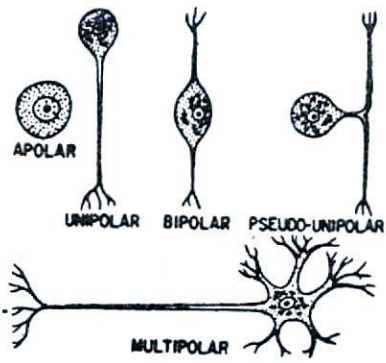


FIG. 5.18. Diagram to show basic morphological features of the types of neurones.

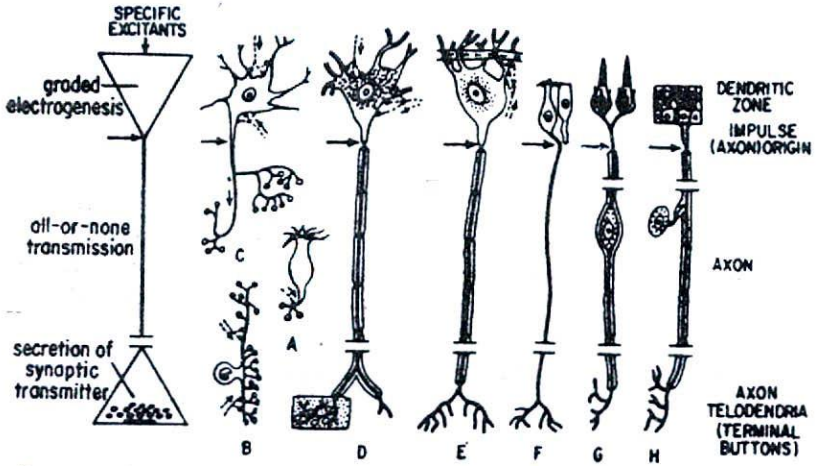


FIG. 5.19. Diagram of receptor and effector neurones of some mammals with the site of axon (impulse) origin (represented by the arrow) rather than the position of the cell body. The location of perikaryon in the neurone is not critical for the electrochemical function of response generation, conduction and synaptic transmission. The neuroplasm in the interior of the perikaryon is concerned primarily with the outgrowth and maintenance of the axon and dendrites, and metabolic function other than membrane activity. Thus the dendritic zone may be dendrites or cell bodies. The axon conducts impulses to the synaptic (axon) telodendria. A, B and C are interneurones and represent retinal bipolar cell, retinal amacrine cell and anaxonic neurones respectively. D is motor neurone. E, F, G and H represent receptor neurones of the crayfish, olfactory, auditory and cutaneous respectively.

small neurone from the spinal nucleus of the trigeminal nerve, motor neurone from the ventral horn of the spinal cord, etc. Usually the shape depends mainly on the number and position of the dendrites.

An **alternative classification** separates the neurones in two groups: (1) **Golgi type I neurone** has a very long axon which has an extensive course outside that part of the gray matter of the CNS where the cell body lies, and passes in the white matter. these cells form the bulk of the neurones which constitute the peripheral nerves and the main fibre tracts of the brain and spinal cord. (2) **Golgi type II neurone** is stellate and has a short axon which does not leave that part of the gray matter in which the cell body lies. these cells are to be found in the retina, the cerebellar and the cerebral cortices. These neurones vary greatly in size and shape. Spherical, oval, piriform, polyhedral, and fusiform types are described, but all have numerous radiating processes which give them a stellate or star-shaped appearance.

Structure of cell body (soma). The following structures are found in the cell body.

1. **Nucleus.** The nucleus is commonly large, spherical or slightly ovoid and centrally placed within the perikaryon. It varies in size with the size of the cell and with its state of activity. The nerve cell nucleus is a particularly suitable one in which to see the sex chromatin of the female, which looks like a small dark staining body close to the nucleolus or nuclear membrane. Although present in the male, it is too small to be seen under normal conditions.

Chromatin particles in the nucleus are finely dispersed and hence nuclei of the neurones appear rather *pale* and *empty-looking* when stained with basic dies, e.g., thionine. One or two nucleoli are characteristically present.

2. **Neuroplasm.** The neuroplasm or cytoplasmic matrix of the nerve cell contains filamentous, membranous and granular organelles and are arranged more or less concentrically around the nucleus. With a light microscope these organelles are neurofibrils, Nissl bodies or chromophilic substance, Golgi apparatus, mitochondria, a centrosome. A considerable number of inclusions are also found.

(*a*) **Neurofibrils.** Fine filaments, passing through the neuroplasm, from the dendrite to the axon (Fig. 5.20C).

(*b*) **Nissl Bodies (granules).** Angular granules, staining with basic dyes (methylene blue, thionene or cresyl violet) present in scattered from through the cytoplasmic portion of the cell and dendrites excepting the axon hillock from which the axis cylinder arises. There is no Nissl granule in the axon (Fig. 5.20A). Electron microscopic studies reveal that these basophilic granules are composed of thin, parallelly arranged membrane-bound cavities which are closely akin to endoplasmic reticulum containing cisternae, vesicles and tubules. In dendrites, Nissl granules are rod-shaped. In motor neurones, they are coarse and flocculent while in sensory neurones they are almost dust-like. Chemically, they are supposed to be ribose nucleoprotein containing iron from its staining reaction. there is doubt whether the Nissl substance is present in the living cell. There function is definitely not known but somehow related to the activity of the cell. They disappear following injury to the nerve cell, damage to the processes, loss of function of the neurone, circulatory distrubance, hyperpyrexia, poisons, fatigue, etc. This process is known chromatolysis. When the nerve cell regenerates, the granules reappera. It has been suggested that Nissl granules participate in conduction of nerve impulses.

perhaps by releasing minute quantities of iron which acts as a catalysing agent in increasing the metabolic activity of the cell.

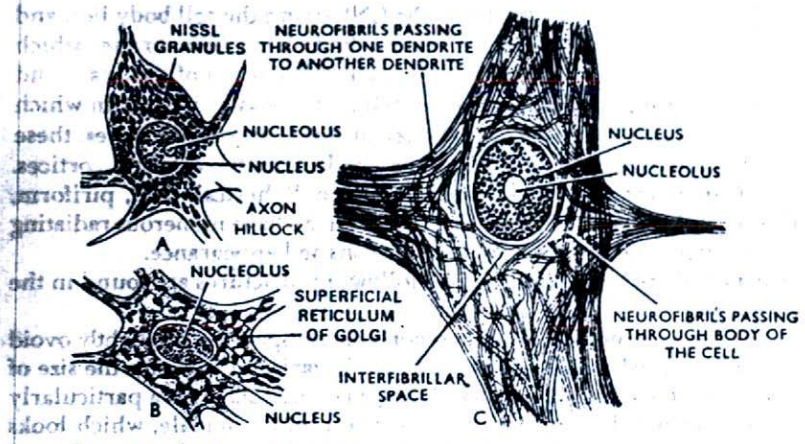


FIG. 5.20. Nerve cells (diagrammatic).
A = showing Nissl granules, B = showing superficial reticulum of Golgi.
C = showing neurofibrils in a cell from the anterior gray column of the spinal cord.

(*c*) **Mitochondria.** Numerous and distinct. They are rod-shaped, spherical and widely distributed. There are phospholipid-protein inclusions which often appear in granules or filaments.

(*d*) **Golgi apparatus.** Highly developed and complex—intracellular reticular network.

(*e*) **Superficial reticulum of Golgi.** A fine network on the surface of the nerve cell (FIG. 5.20B).

(*f*) **Ribosome.**

(*g*) **Endoplasmic reticulum.**

(*h*) **Centrosome.** The spherical centrosome contains a pair of centrioles and is characteristic of the immature, multiplying neuroblasts during early stages of embryonic development. With the optical microscope a typical centrosome is seldom observed in the adult neurone of vertebrates. However, with E.M. a centrosome is often found in the cytoplasm, even though the neurone will never divide. Its role in the neurone is therefore not clear.

(*i*) **Inclusions.** (*a*) *Melanin* is present as dark-brown or black granules in some cell groups, particularly in the substantia nigra of the midbrain, locus caeruleus in the floor of the IVth ventricle, dorsal motor nucleus of the vagus, and in the spinal and sympathetic ganglia. Its significance is not clear. (*b*) *Lipochrome* granules of a yellow or orange colour are seen in certain cell groups, especially in those of the autonomic ganglia and in the region of axon hillock. The amounts of this yellow pigment (*lipofuscin*) increase with age. It is suggested that it represents a by-product of normal metabolic activity. *Lipid* is encountered in the form of droplets in the cytoplasm of nerve cells. *Glycogen* is found not only in embryonic neurones but also in embryonic neuroglial cells, in embryonic cells of the ependyma and choroid plexus. But it cannot be seen in adult

nervous tissue with a histochemical demonstration. *Iron-containing granular deposits* are observed in the nerve cells of the substantia nigra, globus pallidus, etc.

(*j*) **Neurosecretory material.** The hypothalamic neurones of the supra-optic and paraventricular nuclei contain droplets with characteristic staining properties. These are present in the cell body as well as in their axon.

3. **Cell membrane.** The surface or plasma membrane of a neurone appears to be basically similar to that of cells in general. Within the CNS the nerve cells are closely invested by a network of neuroglial cells and fibres, whereas in the peripheral ganglia the nerve cells are surrounded by a capsule of satellite cells of similar origin.

NEUROGLIA

It is a special type of interstitial tissue and is present both in the gray and white matter. According to shape, size and number of processes, three main types have been described: (1) **astrocytes**—(*a*) **protoplasmic** *astrocyte*, and (*b*) **fibrous** *astrocyte* ; (2) **oligodendroglia** or **oligodendrocyte** (few processes); (3) **microglia** (small in size) (FIG.5.22). The first two are ectodermal in origin. But microglia is mesodermal and belong to the reticulo-endothelial system.

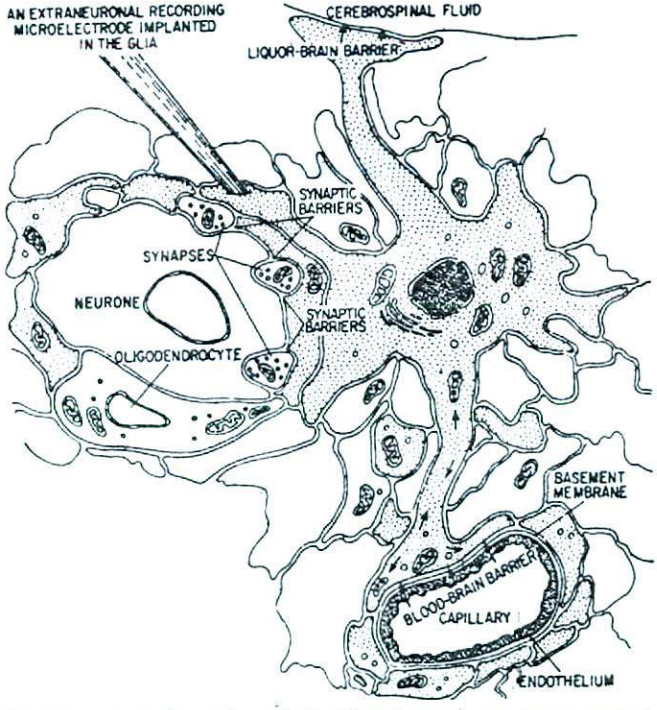


FIG. 5.21. Diagram to show the relationships between an astrocyte and other components of the central gray matter. The astrocyte contracts a capillary, the piaglial membrane and a nerve cell. Arrows indicate possible movemen.* of fluids and solutes within the cytoplasm.

Functions of neuroglia. (1) Support, (2) insulation, (3) phagocytosis. Under pathological conditions the microglia becomes amoeboid and phagocytic and wander in the meninges and blood vessels in the central nervous system. Their number is increased during inflammation. (4) Astrocytes are found around the blood vessels wall and appear to serve as

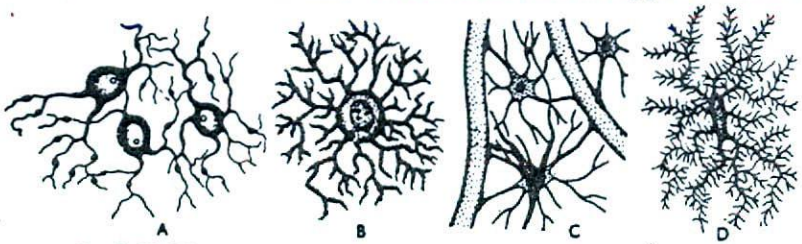


FIG. 5.22. Diagrammatic representation of the neuroglial cells showing A=Oligodendroglia, B=Protoplasmic astrocyte, C=Fibrous astrocyte, and D=Microglia.

regulator of the ionic environment of the neurones and are thought to make up the **blood-brain barrier** (Fig. 5.21). (5) Like the Schwann cells (*oligodendroglia*) (oligodendrocyte) takes part in the formation of myelin sheath in the central nervous system.

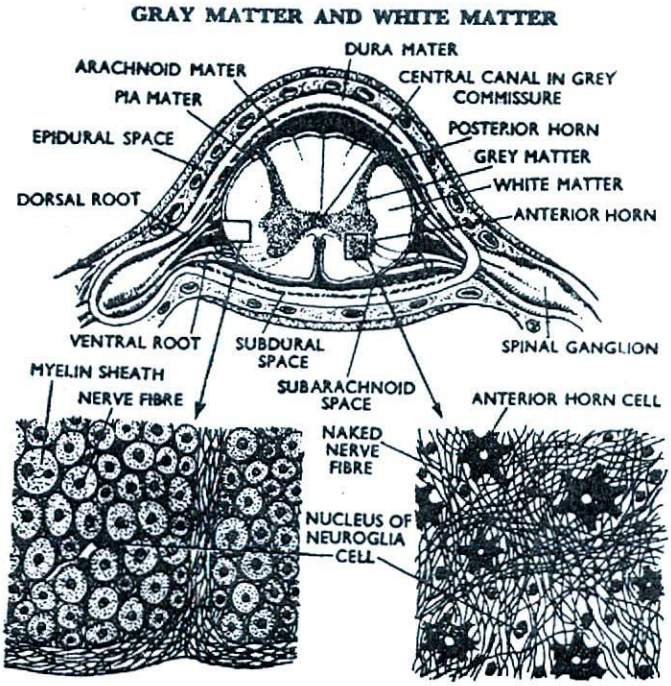


FIG. 5 23. Diagrammatic representation of the distribution and contents of the gray and white matter in the cross-section of the spinal segment.

Gray matter is composed of the nerve cells and *white matter* is composed of the nerve fibres. The white colour is due to the myelin sheath. **Distribution.** In the cerebrum and cerebellum, the gray matter remains on the surface, while the white matter in the interior. In the spinal cord the arrangement is reversed—the gray matter being in the centre while the white matter outside (Figs. 5.23 & 5.24).

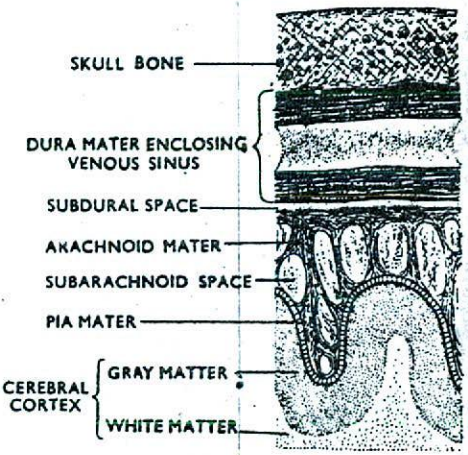


Fig. 5.24. Diagrammatic representation of the distribution and contents of the gray and white matter in the section of the brain.

Myelin sheath

So long as the nerve fibre is within the gray matter, it remains naked. As soon as it enters the white matter, it gets the first covering, the *myelin sheath* (white). When it comes out of the central nervous system it receives a second covering—the *neurolemma* (*neurilemma*). When the nerve fibre terminates at the periphery, the neurolemma is lost first, then the myelin sheath and lastly, the axis cylinder. The latter ends as a naked process without any covering (*vide* Nerve Endings).

Each motor fibre at its termination breaks up into about 150 branches, each of which ends in a separate muscle fibre. *One motor nerve fibre, with all the muscle fibres that it supplies, constitutes one* **motor unit.** *Each unit is controlled by one motor nerve cell.*

Myelination in the peripheral nerve fibre

In a **myelinated nerve fibre,** the central core is the axon. The surface of the axon is the actual conducting membrane (Fig. 5.25). The axon is filled with a viscous intracellular fluid which is called *axoplasm.* The

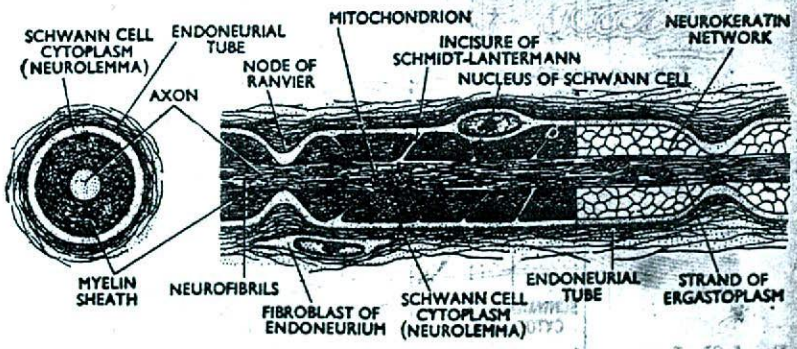


Fig. 5.25. Diagrammatic representation of a cross-section (*left*) and longitudinal section (*right*) of peripheral myelinated nerve fibre with the endoneural sheath.

axon is surrounded by a *sheath of lipid material* which is known as *myelin*. The myelin sheath is prolonged all over the thick somatic nerves but not over the postganglionic autonomic nerves. The somatic nerves of 1 μ diameter are not medullated. The preganglionic autonomic fibres are medullated. In the somatic nerves the myelin sheath is lined by a delicate membrane of flat cells, which is known as neurolemma or sheath of Schwann. The sheath of Schwann has got cell which is known as Schwann cell. It has got nucleus which is located near the outer membrane of the cell. The nucleus and the irregular cytoplasmic strand constitute the Schwann cell of matured nerve fibres. This Schwann cell takes part in the deposition of myelin sheath—myelinogenesis.

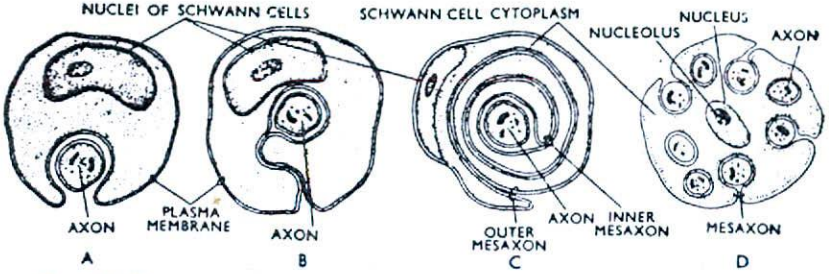


FIG. 5.26. Diagrammatic representation of the process of myelination from A to C in the peripheral nerve fibre and showing the axon of the unmyelinated fibres to bathe within the Schwann cells in D.

Myelinogenesis in the peripheral nerve fibre. In the peripheral nerves (somatic nerves) *myelinogenesis* begins with the deposition of myelin sheath round the axon by the Schwann cells. The axon is first enveloped

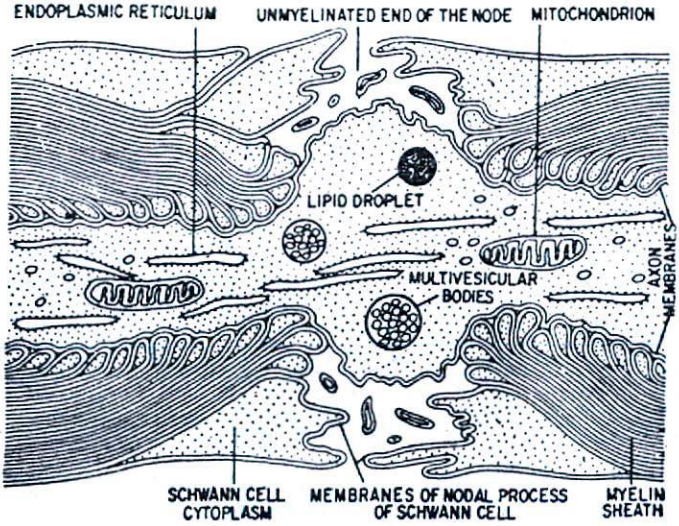


FIG. 5.27. Diagram of a node of Ranvier showing gap between membranes of nodal processes of Schwann cells and axon membranes over unmyelinated fibres.

completely by the Schwann cell membrane. The Schwann cell membrane then gives several turns leaving the axon surrounded by many concentric layers (FIG.5.26C). The cytoplasm disappears from the concentric layers leaving only the cell membrane and it is retained only in the exterior turn and also in the interior turn, next to the axon. The *inner mesaxon* is present where the Schwann cell completes its second turn around the axon. The *outer mesaxon* is present at the junction where the Schwann cell completes its outermost turn. The compact myelin consists of several concentric layers of the Schwann cell membrane. This Schwann cell membrane also consists of outer and inner layers of protein separated by a lipid substance *sphingomyelin* (FIG.5.26A–C). This substance acts as insulator and prevents almost all flow of ions. The medullated fibres are not continuous with the myelin sheath but interrupted regularly at an interval by the node of Ranvier. In the node of Ranvier, myelin is absent and the Schwann cell membrane is dipped inwards over the axon (FIG.5.27). In comparison with the myelin sheaths the neurolemma in the region of the node of Ranvier is highly permeable to ions.

In case of unmyelinated fibres, the axons are buried within the Schwann cells (FIG.5.26D).

Myelinogenesis in the central nervous system

In the central nervous system there is no neurolemma and myelination takes place by the presence of oligodendroglia cells which surround the axon and form the myelin. Like peripheral nerves, the nerve fibre of the central nervous system possesses nodes of Ranvier but these are not so obvious as in peripheral nerves.

Chemical composition of the nervous system

In the living resting state, the nervous tissue is slightly alkaline. During activity and after death it becomes acid. *The chief characteristic of nervous tissue is the high cholesterol and phospholipid content.* The **gray matter** contains more water and less solid than the **white matter.** The average composition of the gray and white matter is as follows:

Water—*white*—70% (*gray*—**84%**).
Solids—*white*—30% (*gray*—**16%**).

(1) **Protein**—*white*—10% (*gray*—**8%**). It includes (*a*) *globulins*, (*b*) *nucleoproteins*, specially in the nerve cells, and (*c*) *neurokeratin* in the medullary sheath.

(2) **Fats**—*white*—13·5% (*gray*—**4·4%**). This includes (*a*) *phospholipids: white*—8·5% (*gray*—**3·7%**)—lecithin, cephalin, sphingomyelin, (*b*) *cholesterol. white*—5% (*gray*—**0·7%**), and (*c*) traces of *neutral fats.*

(3) **Carbohydrates**—*white*—5% (*gray*—**3%**). It includes (*a*) *cerebrosides* also called **galactosides.** They are nitrogenous glucosides yielding galactose on hydrolysis. Three varieties are known—*phrenosin, kerasin* and *nervon.* (*b*) Traces of *glucose* and *glycogen.*

(4) **Inorganic salts**—*white*—0·8% (*gray*—**0·8%**). This includes potassium salts mainly but also contains Na^+, Ca^{++} and traces of other inorganic salts.

(5) **Extractives**—in traces. It includes ammonia, lactic acid, creatine phosphate, adenyl pyrophosphate, etc.

It is to be noted that the amount of all the solids is more in white matter excepting the inorganic salts, which is almost the same in both white and gray matter.

Nerve Fibres

PHYSIOLOGICAL PROPERTIES OF THE NERVE FIBRE

Physiological properties of the nerve fibre can be studied through the **cathode ray oscilloscope (CRO).**

Studies of action potential or membrane potential. *Action potential or membran potential* of a single nerve fibre can be studied by microelectrode placed within the nerve fibre and a differential electrode placed outside the nerve fibre. Each mircoelectrode is a minute capillary glass tube with a tip of 0.25 to 2 microns filled with a very concentrated potassium chloride solution acting as an electrical conductor. The other ends of both the electrodes are connected to the **cathode ray oscilloscope (CRO).** The development of action potential in the nerve fibre is viewed on the oscilloscopic screen of the CRO.

Cathode ray oscilloscope (CRO)

The cathode ray oscilloscope is used estimate or measure the electrical changes of the living tissues. A cathode emits electrons when a high voltage is applied to it with a suitable anode in a vacuum. These emitted electrons are directed into a focused beam which strikes the face (screen) of the glasstube of the CRO. The screen of the CRO is coated with a number of fluorescent substances (*phosphors*) which emit light when struck by electrons. In a CRO to record the action potentials two electrical circuit must be employed which are as follows : (*i*) an *electronic sweep circuit* and (*ii*) an *electronic amplifier.* The

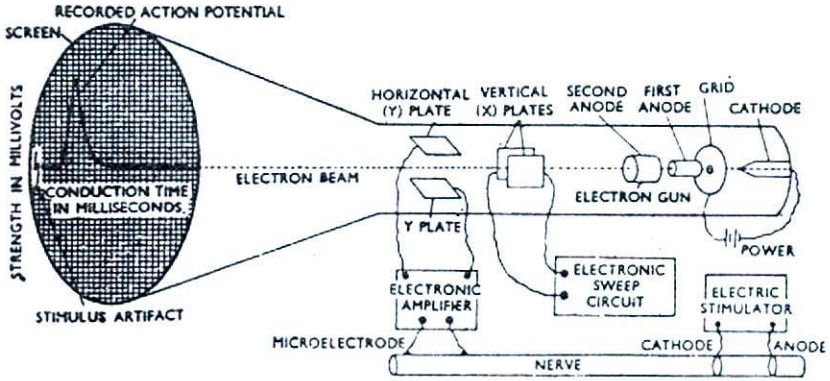


FIG. 5.28. Simplified, diagrammatic representation of the main connections of the CRO to action potential changes.

electronic sweep circuit is connected with two vertical metal plates (*X-plates*) on either side of the beam in the cathode ray (CR) tube. By altering the electrical potentials at a very high speed it moves the beam of electrons horizontally across the screen of the tube from left to right and when the beam reached the right extremity, it jumps back to the left side and in this way the beam is always moving from to right. There are two metal plates, in the cathode ray tube, which arranged *horizontally, one above and the other below* the electron beam. The *Y-plates (horizontal)* are connected, with the electronic

amplifier. This set of deflecting plates move the electron beam up and down with the change of action potential in them. For experiments, the electrodes are placed on the nerve fibre or the tissue of which the electrical potential change is to be measured. These electrodes are connected with the amplifier circuit thereby to the *horizontal plates* (*Y-plates*). The potential change in the tissues after proper amplification is transmitted to the Y-plates and recorded as vertical deflections of this electronic beam on the screen which may be photographed for permanent record. Within the CR tube itself, cathode serves as a source of electrons, *grid* controls the intensity of electron beam and brightness of the spot. The *first anode* compresses the flow of electrons into narrow beam whereas the *second anode* (*electron gun*) is highly positive and accelerates the beam of electrons. The electric stimulator, of which one is connected with cathode and the other with anode, applies a short (or as chosen) voltage (*pip*) to the nerve stimulating microelectrodes (FIG. 5.28).

Nerve fibres show the following properties: (1) **Excitability.** (2) **Conductivity.** (3) **All-or-none law.** (4) **Refractory period.** (5) **Summation.** (6) **Adaptation.** (7) **Accommodation.** (8) **Indefatigability.**

1. **Excitability.** The nerve fibre can be stimulated by a suitable stimulus, which may be *mechanical*, *thermal*, *chemical* or *electrical*. In experiments, electrical stimulation is usually employed, because its strength and frequency can be accurately controlled. The following changes will show

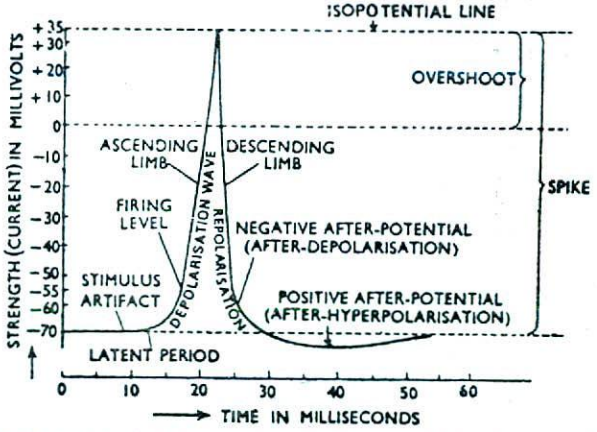


FIG. 5.29. Diagrammatic representation of spike potential (action potential) recorded with the help of microelectrode in the nerve cell.

that a nerve has been excited: (*a*) The muscle or the gland where the nerve ends will respond. (*b*) The stimulated spot on the nerve becomes electrically negative and this wave of negative potential passes along the nerve and can be detected by galvanometer or by CRO. (*c*) *The action potentials* —An electrical disturbance always accompanies the travelling nerve impulse. In resting cell the surface is positively charged and the interior is negatively charged. When the surface is stimulated and the permeability is increased as a result there is reversal of polarisation. The surface at the stimulated point becomes negative (*cathode*) causing catelectrotonic change.

When this change rises to threshold level, impulse will pass like self-propagated disturbance by drawing positively charged particles from the neighbouring points which in turn becomes cathode. The depolarisation of the membrane is the first step of the manifestation of an impulse. After an initial slow rise, depolarisation wave overshoots rapidly and reaches the isopotential line (zero line) to approximately +35 mV. After that it reverses and begins to fall very rapidly towards the resting level (−70 mV). At approximately two-thirds of repolarisation, the rate of fall is being abruptly slowed. This slower fall is known as *negative after-potential* (*after-depolarisation*). The rapid rise of depolarisation wave and the rapid fall of repolarisation wave are known as *spike potential*. After reaching the basal level the wave overshoots slightly but slowly in the hyperpolarising direction. This is known as *positive after-potential* (*after-hyperpolarisation*). The whole sequence of potential changes in the nerve following excitation is known as *action potential* or *membrane potential* (FIG.5.29).

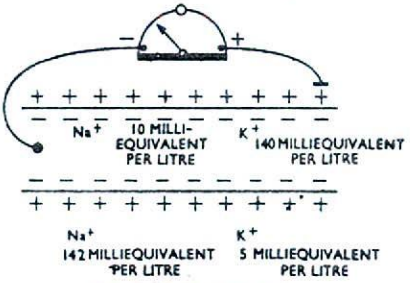


FIG.5.30. Resting state.

Mechanism of the development of action potential

In resting state the nerve fibre remains in polarised state and the membrane potential lies within −70 mV. The inside of the nerve is negative and the outside of the nerve is positive (FIG.5.30). Na^+ concentration

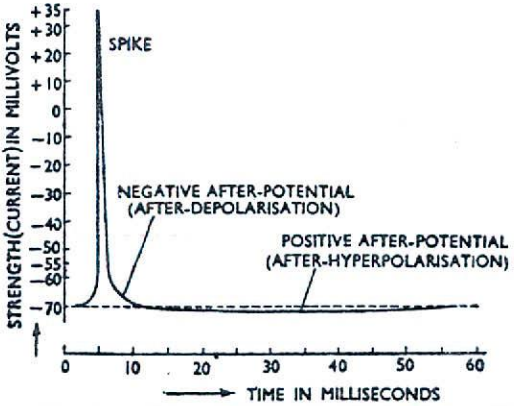


FIG.5.31. Diagram to show complete action potential of a large mammalian medullated fibre drawn without time or voltage distortion to represent proportions of components.

outside the membrane is higher than that of inside the membrane. K^+ concentration inside the membrane is also higher than that of outside the membrane. K^+ can permeate through the membrane at resting state but the Na^+ cannot permeate. Permeability of Na^+ to membrane is increased

only after excitation and it is the *first event* of the action potential. The action potential occurs in successive stages of depolarisation, repolarisation, negative after-potential and positive after-potential (FIG. 5.31). It has been postulated that in resting state calcium ions (Ca^{++}) remain binding to the protein surfaces of the membrane pores and it does not allow Na^+ to permeate through these resting pores. During excitation Ca^{++} is dislodged from its binding site and the permeability to Na^+ is increased. So the depolarisation starts with the onset of Na^+ entry and thus an increase in Na^+ conductance is taken place. The tremendous increase is Na^+ conductance during this period is known as **activation of membrane.** Due to this, the *reversal* of potential is caused with the development of positivity inside the membrane and negativity outside (FIG. 5.32). But

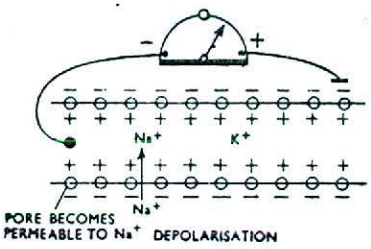


FIG. 5.32. During activation of the membrane.

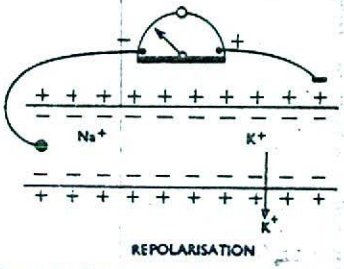


FIG. 5.33. Potassium efflux during the repolarisation.

with the increase of positivity inside, further entry of Na^+ is prevented and calcium begins to bind with the proteins of the membrane pores. But as soon as the action potential attains the voltage approximately +35 mV, K^+ begins to come out from inside the membrane. The inside becomes negative and outside becomes positive again (FIG. 5.33). This stage is the repolarisation phase and K^+ conductance is increased to the maximum. The mechanism underlying the process of K^+ conductance is mostly hypothetical and increased positivity inside the membrane due to Na^+ entry during depolarisation phase, allows the K^+ to come out and the resting potential is slowly achieved. But at the later period of this phase (at the termination of spike potential) K^+ conductance is slowed down and thus a few milliseconds are delayed in restoring the membrane potential. This state is known as negative after-potential which has been described to be the cause of increased K^+ concentration outside the membrane. This increased K^+ concentration may hinder further efflux of K^+. With the disappearance of the negative after-potential, though the resting membrane potential is achieved yet the resting ionic status is not established. It is achieved by the active Na^+ *pump mechanism* and Na^+ begins to come out from

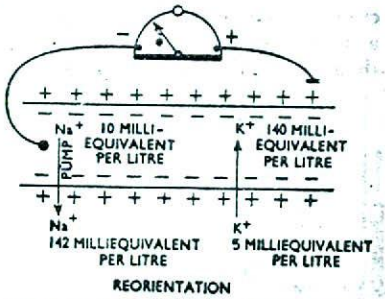


FIG. 5.34. Diagram shows the reorientation of ions for achievement of resting ionic status as well as resting membrane potential by sodium pump.

inside the membrane creating negativity again (Figs. 5.34 & 5.35). The *positive after-potential* is due to this process of Na^+ diffusion from inside to outside the membrane.The negativity, produced due to active Na^+ pump mechanism, causes the K^+ to diffuse back to the interior of the nerve fibre. For the active Na^+ and K^+ pump mechanism high energy phosphate (ATP) is required. In this way resting normal ionic status is established during the period of positive after-potential.

Excitablity depnds upon the following factors : (i) strength of stimulus — A minimum stren gth is essential. (*ii*) *Duration* of stimulus — The **stimulus** must continue for a certain minimum period, which varies inyersely as the strength. Excitability of a nerve fibre can be determined by studying its strength-duration relationship (threshold stimulus intensity duration) of the stimulus. Current intensity of stimulus which is just adequate to cause an impuse is called the *threshold*. Intensity below the threshold is known as *subliminal*. Magnitude of current just sufficient to excite a nerve or muscle is called **rheobase** and the minimum time required to have a response is known as *utilisation time*. The shortest duration of current flow which will excite the nerve or muscule under current strength equal to *twice* the rheobase is called the *chronaxie*. **Chronaxie** value is a useful index of the relative excitability of the tissues. To obtain an *excitability curve*

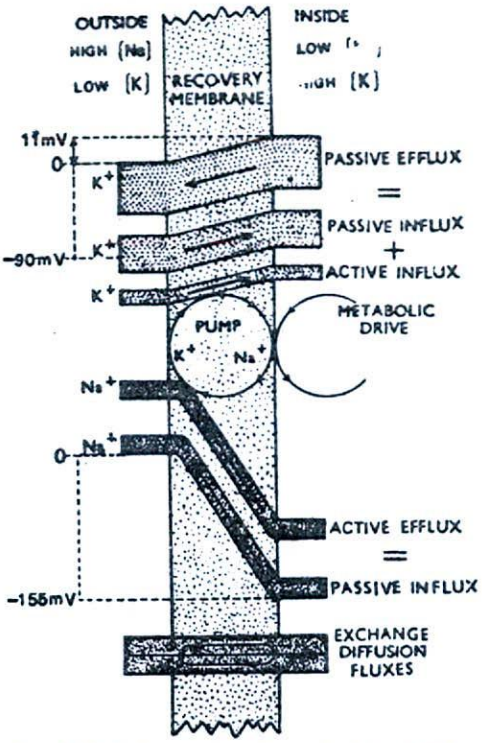


FIG. 5.35. Sodium pump is required to expell sodium from the interior of the nerve axon so that the internal sodium concentration is held to about 7% that of the external fluid. At the same time pump drives potassium *uphill* from a lower external concentration to about 28 times higher internal concentration.

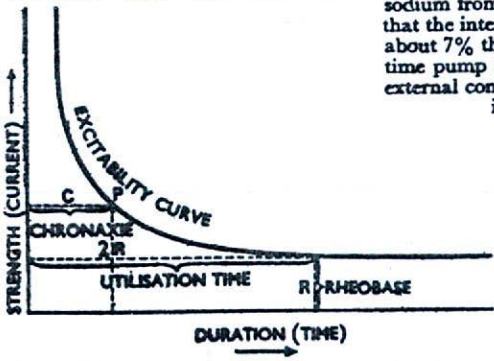


FIG. 5.36. Diagrammatic representation of excitability curve (strength-duration curve) applied to an excitable tissue producing response relating the strength of stimulus.

(strength-duration curve) a minimum current strength for exciting a nerve or muscle is first determined and chronaxie is then obtained by determining the shortest duration of stimulus with double the *rheobase voltage* (FIG. 5.36). (*iii*) *Direction* of the current—If the current is passed transversely across the nerve no effect will be produced. When it passes along the length of the nerve there is the maximum chance of stimulation. (*iv*) *Frequency* of stimulus—Usually one stimulus generates one nerve impulse, but if the stimulus be strong, more than one impulse may follow. Ca^{++} lack increases this tendency of multiple response. (*v*) *Injury*—Excitability is increased near the site of injury. But later on it becomes depressed, and this depression slowly travels down the nerve, so that excitability disappears last from that part of the motor nerve which is nearest to the muscle.

Compound action potential. Action potential recorded from a group of nerve fibres (e.g., sciatic nerves) or a nerve trunk is called compound action potential as it is the summated action potentials of different types of nerve fibres having different conduction velocities (FIG. 5.37). The multipeaked shape of the compound action potential is due to the activity of the different nerve fibres of varying conduction velocity. Most nerves are composed of myelinated nerve fibres of various diameter and also unmyelinated fibres of quite large number. The results obtained by stimulating one end of a frog nerve and recording from a point as far away as possible were described by Erlanger and Gasser. With a large shock, the action potential appears as in FIG. 5.38. It is conventionally split into three waves called A, B, C. The A wave itself is divided into α, β, γ and δ sections (FIG. 5.39). The A wave

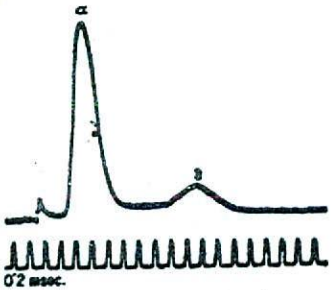


FIG. 5.37. Compound action potential.

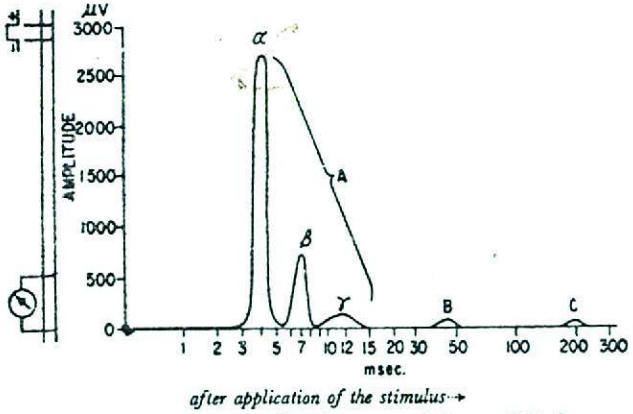


FIG. 5.38. It showing a compound action potential as might be recorded from any nerve containing both myelinated and unmyelinated fibres. The A wave represent myelinated fibres and the C wave unmyelinated ones. The B wave may be mixed.

represents activity in myelinated axons and the C wave that in unmyelinated axons. The B wave may represent both types. The reason for the spreading out of the waves lies in the differing conduction velocities of the fibres. If the recording electrode is close to the stimulating electrode, only a single wave can be detected. It is possible to activate selectively the axons of different sizes. With small shocks, only the α wave is apparent. As the shock strength is increased, so other components of the A wave appear, followed by the B and C waves. The largest, fastest-conducting fibres thus have the lowest threshold to stimulation. If a maximum shock (one which fires all the fibres) is used, and pressure is carefully applied between the stimulating and recording electrodes, another phenomenon becomes apparent. The pressure blocks conduction in the largest fibres first. The α wave is the first to go, followed by β, γ, δ and B until only the C wave is left. By adjusting both the stimulus strength and the pressure it is thus possible to record any component of the action potential. For example, if it is desired to fire γ fibres alone, the stimulus strength will be increased until α, β and γ wave appeared and then knock out the α and β components by application of a pressure block.

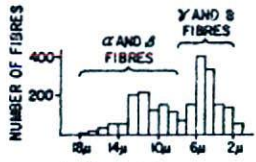


FIG. 5.39. The graph showing the numbers of myelinated nerve fibres of different diameters in nerve.

2. **Conductivity.** The nerve impulse is conducted along the nerve fibre. Conductivity shows the following characteristics : (*i*) Impulse is propagated along a nerve in both directions. [But under normal conditions the nerve impulse travels in one direction only — in the motor nerve towards the responding organ ; in the sensory nerve towards the centre. This is due to the action of 'synapse'.] (*ii*) *Velocity of nerve impulse* — The nerve impulse is propagated with a definite speed (other conditions remaining same). The conduction velocity depends upon the diameter of the nerve fibres, the thicker fibres showing higher velocity. The conduction velocity also depends upon the presence or absence of myelination and also on temperature.

Conduction velocity of a bundle of nerve fibres can be studied by stimulating the nerve bundle at one end and recording compound action potential at other end. If the length of nerve in mm from the placements of the stimulating electrodes to the recording electrodes is noted then the conduction velocity V (m/sec.) can be calculated easily by dividing this lengh of nerve fibres (L) with the latency (in msec.) of action potential : V (velocity in m/sec.) = L (length of the fibre in mm)/latency in msec. (Fig. 5.40).

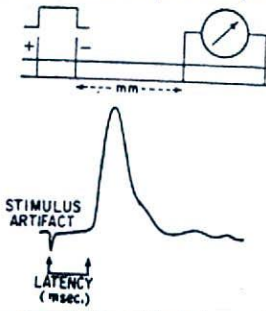


FIG. 5.40. Calculation of conduction velocity.

In general, greater the diameter of the nerve fibre, higher is the velocity of conduction. Velocity/diameter ratio of a mammalian nerve fibre has been worked out to be 6 (**Hursh factor**). If the diameter of the fibres is known then the conduction velocity can be worked out by simply multiplying the diameter (in μ) with the ratio 6. Conversely if the conduction velocity (m/sec.) is divided by the ration 6 then the diameter (in μ) can be found out. The ratio 6 has been considered for peripheral nerve fibres.

The conduction velocity of peripheral nerve fibres in man has been studied intensively and it lies in between 60 and 120 m/sec. Recently Dash (1971) has studied the conduction velocity of ulnar nerve in man and maximum velocity was found to be 67 m/sec. in room temperature. After determining the diameter of the whole ulnar nerves histologically, he has derived the conversion factor to be 5 for ulnar nerve in man.

Temperature has got an immense role in conduction of nerve impulse. In the cold-blooded animal conduction velocity is lower than those of the warm-blooded animal. In the largest nerve fibres the speed of action potential is about 20 metres per second in the frog at 20°C. and about 120 m/sec. in mammals at 37°C. In Amphibian nerve, the conduction velocity is comparatively low (17–40 m/sec.) than that of the mammal.

The conduction velocity of myelinated fibres is proportional to the diameter of nerve fibres. The conduction rate in m/sec. is approximately 6 times the fibre diameter in microns in fibres larger than 3μ.

The unmyelinated fibres have a conduction velocity proportional to the square root of the diameter of nerve fibres. With a diameter of 1μ the conduction velocities are approximately the same. Below 1μ unmyelinated fibres have a faster conduction rate than myelinated fibres.

Factors affecting conductivity and excitability. (*a*) *Temperature*—cooling diminishes and warming increases these properties. (*b*) *Mechanical pressure*—depresses conductivity and excitability. (*c*) *Blood supply*—If blood supply be cut off both these properties are lost. (*d*) *Chemicals*—CO_2 and narcotics, viz., ether, chloroform, alcohol, novocain, etc., diminish and finally abolish excitability and conductivity. (*e*) *H-ion concentration*—increased pH (*alkali*) increases and decreased pH (*acid*) diminishes. At pH 8·0 the nerve becomes hyperexcitable and spontaneous discharge may occur. Even a single stimulus may cause multiple response (repetitive response). (*f*) *Effect of ions*—lack and excess of Ca^{++} have the same effects as rise and fall of pH respectively. Changes of K^+ exert opposite effects. Na^+ and Mg^{++}—similar to K^+ but less in degree (hence, Na^+, K^+ and Mg^{++}—are *neuro-excitatory, while* Ca^{++} is *neurosedative*). (*g*) O_2 *lack*—depresses and if continued abolishes these properties. If O_2 is readmitted, they return.

3. **All-or-none law.** If the stimulus be adequate a single nerve will always give a maximum response. If the strength or duration of the stimulus be further increased no alteration in the response will take place. This property is present in single fibre preparation. In the whole nerve this property is different.

4. **Refractory period.** When the nerve fibre is once excited, it will not respond to a second stimulus for a brief period. This period is called *absolute refractory period.* The absolute refractory period means that the nerve is completely refractory to stimulation—in other words is incapable of eliciting an action potential at any intensity of stimulation. During the absolute refractory period there is total inactivation of the sodium carrier mechanism and as the Na^+ ions cannot enter the fibre, there is no development of the action potential. Immediately following this, there is a brief *relative refractory period,* during which the excitability is subnormal but gradually rising. This is succeeded by a third brief period of increased excitability, known as *supernormal phase.* Lastly, there is a period of subnormal excitability—*subnormal phase.*

Fig. 5.41 demonstrates the different refractory periods. When two stimuli are applied to one end of a nerve at different time intervals, compound action potentials are recorded and two different action potentials are recorded (I, II). But as the time intervals are gradually decreased, a time will come when the second shock will fail to produce compound action potential of equal length and the height will be decreased (III, IV). This is happened in absolute refractory period. But if the time interval is further decreased, then the second stimulation will fail to elicit any response. This period is the absolute refractory period (V). In the large mammalian nerve fibres the durations are as follows: Absolute refractory period—2 to 3 milliseconds in frog but in mammal it is 0·5 millisecond. Relative refractory period—10 to 30 milliseconds in frog but in mammal 3 milliseconds. Supernormal phase—12 milliseconds and subnormal phase—up to 70 milliseconds.

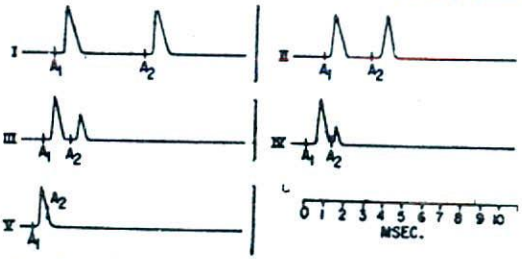


Fig. 5.41. It shows the nature of action potential recorded by successive stimuli at different intervals.

5. **Summation.** (*Latent addition*). In a nerve fibre summation of two submaximal stimuli is possible.

6. **Adaptation.** The nerve fibre quickly adapts itself. Due to this adaptation there is no excitation during the passage of a constant current. Only when the strength of the current is suddenly altered or the current is made or broken excitation takes place. A gradual change will fail to excite.

7. **Accommodation.** If a stimulus even with stronger strength is applied very slowly to a nerve, then there may have no response only due to lack of attaining the threshold strength. This phenomenon is called accommodation, i.e., slowly applied stimulus is accommodated by the nerve no matter how strong the stimulus is applied.

8. **Indefatigability.** In the nerve muscle preparation, if the nerve is stimulated repeatedly, then after a certain period the muscle fails to give any response. Now if that nerve is isolated from the muscle and placed on a fresh muscle, then application of stimulus will excite the muscle. This shows that nerve is not fatigued.

Classification of the nerve fibre

Nerve fibres have been classified in different ways: (1) **Histologically**—medullated and non-medullated (*vide* pages 66–68). (2) **Functionally**—motor (efferent) and sensory (afferent). (3) **Chemically**—adrenergic (producing norepinephrine) and cholinergic (producing acetylcholine). (4) **According to diameter and conduction velocity** (Erlanger and Gasser)—The physiological properties of nerve fibres vary with their diameter and conduction velocity. Thicker the fibre, higher will be the impulse velocity and spike potential but lower will be the refractory period and stimulus threshold (chronaxie). Erlanger and Gasser

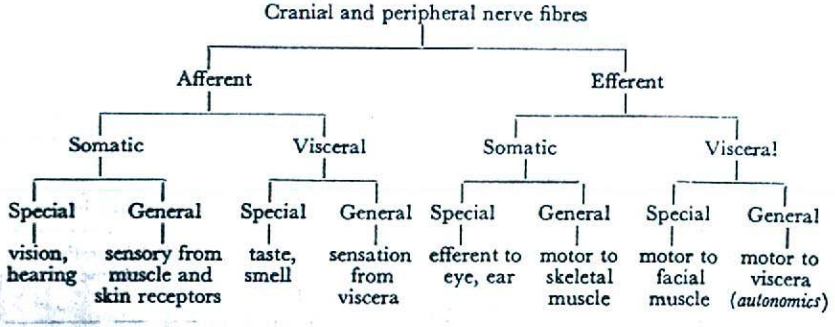
have divided the nerve fibres into A, B and C. On systematic examination of the compound action potential of various nerves, it reveals that A fibres are myelinated, somatic, afferent and efferent axons, B fibres are preganglionic, myelinated, efferent, sympathetic axons and C fibres are sympathetic and somatic, unmyelinated axons. C fibres are of two types—the s.C groups of fibres are efferent, postganglionic sympathetic axons and the d.r.C groups of fibres are the small afferent axons found in peripheral nerves and dorsal roots. In a peripheral somatic fibres both A and C fibres are present. If such fibres are stimulated at one end and recorded through oscilloscope at other end, then the compound action potential formed in A fibres is of four different deflections—α, β, γ and δ. These different deflections are due to corresponding stimulation of different fibres of different conduction velocities. α-deflection is due to stimulation of nerve fibres having comparative larger diameter with higher conduction velocity. δ-deflection is due to stimulation of fibres having lowest diameter and slowest conduction velocity. The B fibres are histologically indistinguishable from small A fibres but distinguishable principally from A fibres by the absence of negative action potential. C fibres in somatic nerve bundle are stimulated only when the threshold stimulus is higher than the stimulus is used in case of A fibres. Functionally the C fibres are distinguishable from the A fibres by slow conduction velocity, long spike duration, high electrical threshold. The C fibres are differentiated into two groups—the s.C and d.r.C on the basis of differences in their after-potential. The s.C group has got pronounced negative and positive after-potentials. The d.r.C group has got no negative after-potential. The following table shows classification according to conduction velocity and diameter of the nerves.

Types of fibre	*Diameter of fibre in μm*	*Velocity of conduction in m/sec.*	*Duration of spike potential in msec.*	*Absolute refractory period in msec.*	*Function*
A-α	12–20	70–120	0·4–0·5	0·4–1·0	Proprioception; somatic motor
A-β	5–12	30–70	,, ,,	,, ,,	Touch, pressure
A-γ	3–6	15–30	,, ,,	,, ,,	Motor to muscle spindle
A-δ	2–5	12–30	,, ,,	,, ,,	Pain, temperature
B	less than 3	3–15	1·2	1·2	Preganglionic sympathetics
C dorsal root (d.r.C)	0·4–1·2	0·5–2·0	2·0	2·0	Pain, reflex response
C sympathetic (s.C)	0·3–1·3	0·7–2·3	2·0	2·0	Postganglionic sympathetics

(5) **Numerical classification of sensory nerve fibres**—Sometimes sensory nerve fibres are numerically classified and have been presented along with Erlanger and Gasser letter system in the following table:

Group	*Letter system*	*Origin*	*Reflex response*	*Central reflex connection*	*Destination*
Ia	A-α	Muscle spindle, Annulo - spiral spindle ending	Myotatic reflex of muscle (*Tendon jerk*)	Monosynaptic with motoneurone of muscle of origin	Spindle of extensor or flexor muscle
„	„	„	Relaxation of antagonist muscle during myotatic contration of agonist muscle	Disynaptic with antagonist motoneurone	Antagonist muscle
Ib	„	Golgi tendon organ	Reaction lengthened	Disynaptic with motoneurone of muscle of origin	Muscle of origin
II	A-β and A-γ	Muscle spindle Flower - spray ending skin, touch-pressure receptors	Relaxation of extensors and excitation of flexors (Flexor withdrawal)	Polysynaptic	Extensor and flexor motoneurones
III	A-δ	Muscle and skin, pain-temperature receptors	Flexion withdrawal of same limb, crossed extensor of opposite limb	„	„
IV	Dorsal root C fibres	Muscle and skin, pain receptors	„	„	„

(6) **On physio-anatomic basis**—On physio-anatomic basis, the peripheral nerves can be classified into afferent and efferent and each of which is again subdivided as presented in the following table:



Metabolism in nerve fibres

Metabolic changes are constantly going on in a nerve fibre at a very low level. During activity the metabolic rate increases. It is known by the

following facts: (*a*) **Oxygen consumption and CO_2 production**—Nerve fibres continuously use O_2 and evolve CO_2. The resting sciatic nerve fibre consumes about 0·7 cu. mm of O_2 and evolves about 0·6 cu. mm of CO_2 per gram of nerve fibre per minute, the R. Q. being 0·8. During activity the extra metabolism consumes about 0·25 cu. mm of O_2 and produces slightly smaller amount of extra CO_2 per gram of nerve fibre per minute. The R. Q. of this extra metabolism is about 0·99. The extra O_2 consumption during activity occurs during the period of evolution of delayed heat. When the frequency of stimulation is raised the total O_2 consumption increases but that per impulse, proportionally decreases. Increasing the strength of the stimulus above the threshold value does not increase the O_2 consumption. (*b*) **Chemical changes and their relation with the properties of nerve fibres**—An elaborate study has been carried out in this respect but the quantity of changes being small and consequently their detection being difficult, opinions vary as to the details of the chemical changes those take place in the nerve during rest and activity.

The following is a brief summary: (*i*) Unlike muscles, the excitability, conductivity and the recovery process can go on in a nerve for a considerable period even in absence of oxygen. (*ii*) The chemical changes in the nerve are roughly of the same nature as seen in the muscles. Pyruvic acid is formed and if O_2 supply be insufficient, lactic acid accumulates (same as in muscles). Thiamine which is essential for complete oxidation of these acids, is found in good amount in the nerve fibres. Although carbohydrates burn, yet they are not the only source of energy (contrast with nerve cells—which possibly use galactose). The breakdown of phospholipids also takes an essential part here. It is said that, *the energy requirement of the resting nerve is supplied by combustion of sugar and phospholipids mainly. During activity, ATP and creatine phosphate break down and supply energy for the propagation of the nerve impulse.* Both ATP and creatine phosphate are then resynthesised but the source of energy of this recovery process is not known (may be in the same way as in muscles). (*iii*) During activity *acetylcholine* is liberated by the *cholinergic fibres*, while *norepinephrine* by the *adrenergic fibres*. (*iv*) The nerve fibres are rich in K^+ and thiamine. During activity K^+ (and possibly thiamine) diffuses out and Na^+ enters the fibres. This migration of K^+ and Na^+ seems to be intimately related to the properties, viz., excitability, conductivity, etc., of the nerve fibres.

Heat production in the nerve fibre

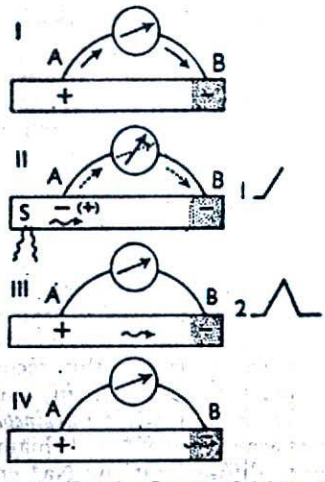
As already mentioned the metabolism in the nerve fibre is very low. During rest a minute quantity of heat is produced which increases during activity. Heat is evolved in three phases: The *first phase* is called *initial heat* and the *other two phases* are seen during recovery and therefore known as the *recovery heat* or the *delayed heat*. **Initial heat**—It is about 10% of the total heat (5–10 microcalories per second per gram of nerve fibre) but the rate of evolution is very brisk being 5000 times greater than that of delayed heat. It is *anaerobic* and coincides with the *spike potential*. Its cause may be the breakdown of ATP, creatine phosphate or, as Hill suggests, due to the discharge of an electric double layer located at the surface of the nerve fibre. **Delayed heat**—It is *aerobic* and is 8·5 times more than the initial heat. This energy is possibly used for the resynthesis of ATP and creatine

phosphate and as such, for restoring the normal excitability of the nerve fibre. It comes in **two stages:** The *first phase* lasts for a few seconds and the quantity of heat is small and is about the same as the initial heat. The *second phase* may last for 10–30 minutes and contributes the greatest proportion of both *total and delayed heat.* Increase in the strength of the stimulus does not raise heat production. But increased frequency increases about 25%. It is to be noted that heat production in the gray matter (nerve cell) is enormously greater than that in the nerve fibre.

Electrical phenomena in the nerve fibre

Besides action potentials which accompany the advancing nerve impulse, certain other electrical phenomena are seen in the nerve fibre.

1. **Current of injury or Demarcation current.** The injured spot on the nerve is electrically negative to the uninjured surface. If the electrodes of a galvanometer or CRO are connected with the injured and the uninjured spots, a current flows from the uninjured (positive) to the injured (negative) spot through the galvanometer or CRO. But through



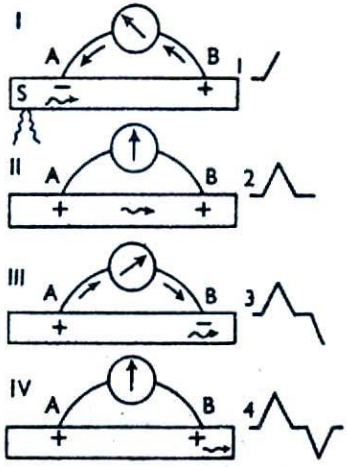


FIG. 5.42. (LEFT)—*Current of injury and Monophasic variation.* Dotted area—damaged part—maximum negative. I. Injured area (B) and uninjured area (A) joined. Current flows from A to B. Needle deflects. This is current of injury. II. Stimulus given at S. Excitation process comes at A and makes it negative or less positive. Hence, less current flows now. So that, the needle moves to a less deflected position. III. Same as I. The needle goes back to the original deflected position. IV. Same as I. Because the excitation wave at B, cannot make it more negative. 1 and 2—Record of needle deflections—corresponding to—II and III—showing monophasic variation—because the needle never crosses the resting line.

FIG. 5.43. (RIGHT)—*Current of action and Diphasic variation.* A, B—Electrodes; S—Point of stimulus, Wavy (Arrow)—Excitation wave (negative—potential). I. Negative potential arrives under A, which becomes negative to B. Hence, current flows from B to A and galvanometer needle deflects to one side. II. Negative potential in the middle, A and B of same potential. No current flows, the needle comes back to zero line. III. Negative wave comes under B and makes it negative. Current flows from A to B, the needle deflects to the opposite side. IV. Excitation process travels beyond B. Both A and B have the same potential. No current flows, needle comes back to the zero position. 1, 2, 3, 4—Record of electrical changes (needle movements) corresponding to I, II, III and IV, showing the development of the diphasic variation—stage by stage.

the nerve it passes from the injured to the uninjured area. This is called *Current of injury* or *Demarcation current* (Fig.5.42).

2. **Current of action.** It is known that the stimulated spot of the nerve fibre becomes negative to the rest of the nerve and that, this negative potential travels along the nerve in both directions with a definite velocity. If two electrodes of a galvanometer are connected with two points along the nerve fibre and then an electrical stimulus is applied on the nerve fibre beyond two poles, it will be seen that the galvanometer needle at first deflects to one side and then to the opposite side of the zero line and ultimately comes back to the resting position. This is due to the fact that when the travelling negative potential overtakes the first electrode, it becomes negative to the other electrode. Hence, a current flows from the latter to the former. Again, when the negative potential overtakes the second electrode, this becomes negative and the current through the galvanometer flows in the reverse direction. This is called *current of action*

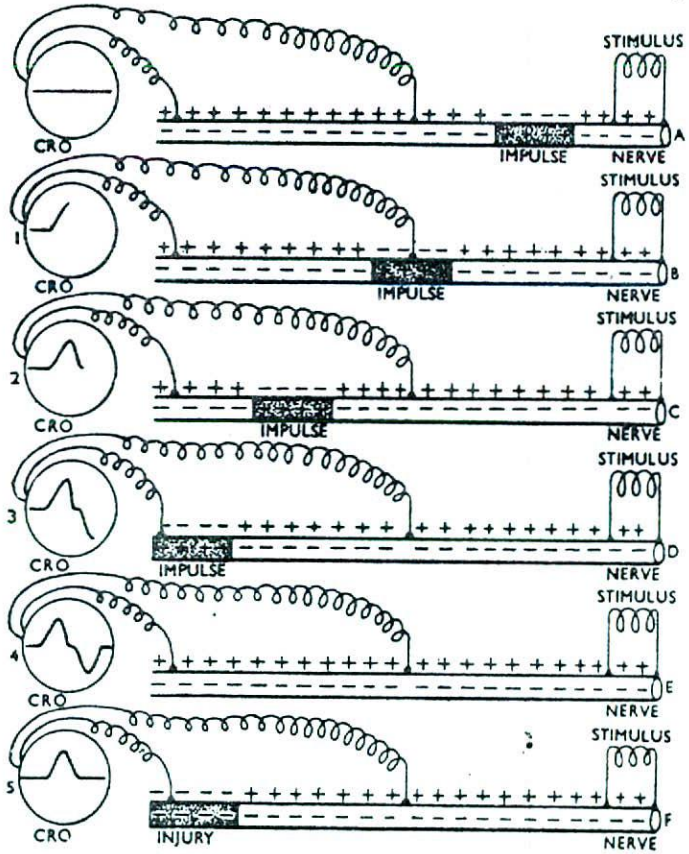


Fig.5.44.Diagrammatic representation of diphasic action potential in the cathode ray oscillograph (CRO) connecting with recording microelectrodes on the outer part of the nerve fibres. Monophasic variation in an injured nerve fibre has also been shown in F.

which is also called **diphasic (biphasic) variation** (FIG. 5.43) due to the two-way movement of the galvanometer needle. This diphasic variation can also be recorded through cathode ray oscilloscope (FIG. 5.44 A–E). Here the galvanometer is replaced by the cathode ray oscilloscope (CRO) and variations in the action potential are viewed through the oscilloscopic screen and the sequential changes in action potential are recorded by a movie camera fitted on the oscilloscopic screen.

If, on the other hand, a current of injury is made to pass through the galvanometer or CRO (by connecting one terminal with the injured and the other with the uninjured spot) and then the nerve is stimulated beyond the electrode connected with the uninjured spot, no biphasic variation will be seen. There will be a **monophasic variation** (FIGS. 5.42 & 5.44F). Because when the impulse arrives at the other electrode there will be no further change, as the part is crushed and damaged; and impulse cannot pass through damaged tissue. Hence, the needle will return to its original deflected position.

3. **Electrotonus.** When a constant current is allowed to pass through the nerve of a nerve-muscle preparation, profound alteration of excitability and conductivity is found to take place in the cathodal and anodal regions. This change of electrical condition is known as **electrotonus.** That around the anode is called **anelectrotonus** and that around the cathode is **catelectrotonus.** The facts regarding electrotonus may be briefly summarised as follows: (*i*) When a constant current is passing through a nerve, the nerve fibre will not be excited. Stimulus arises only at 'make' or 'break'. The 'make' stimulus originates at the cathode and the 'break' stimulus at the anode. (*ii*) Anelectrotonus is a state of depressed irritability and conductivity, whereas catelectrotonus is an increase of these properties. (*iii*) At 'break' these states are reversed, so that the former cathodal region shows a depression and the former anodal region shows an increase in excitability and conductivity. This is called *resolution* of anelectrotonus and catelectrotonus. (*iv*) Thus it will be seen that both catelectrotonus and the resolution of anelectrotonus (around the former anode at 'break') increase the irritability in the corresponding regions. It is due to this rise that 'make' stimulus arises at the cathode and the 'break' stimulus at the anode. (*v*) It should be further noted that the effects due to resolution of anelectrotonus is much less in quantity than due to catelectrotonus. For this reason 'make' stimulus (cathodal) is always stronger than the 'break' stimulus (anodal). So that if the strength of current is gradually reduced, a point will come when the 'break' stimulus will completely drop out and the 'make' stimulus will only be obtained. (*vi*) When the current strength is gradually increased the anelectrotonic depression rises more rapidly and intensely than the catelectrotonic increase of irritability. So that with a moderate current a response will always be obtained. But it may differ in degree. (*vii*) When a strong current is passed, the anodal region is so much depressed that the nerve impulse will be completely blocked when it arrives at this region. Thus with a strong current, the chances of response will depend upon the relative position of the anode and cathode. When the cathode is nearer the muscle (*descending current*) a response will be obtained only at 'make'. When the cathode is away from the muscle (*ascending current*) the muscle will contract only at 'break'. Taking all these facts into consideration if

the nerve it passes from the injured to the uninjured area. This is called *Current of injury* or *Demarcation current* (Fig.5.42).

2. **Current of action.** It is known that the stimulated spot of the nerve fibre becomes negative to the rest of the nerve and that, this negative potential travels along the nerve in both directions with a definite velocity. If two electrodes of a galvanometer are connected with two points along the nerve fibre and then an electrical stimulus is applied on the nerve fibre beyond two poles, it will be seen that the galvanometer needle at first deflects to one side and then to the opposite side of the zero line and ultimately comes back to the resting position. This is due to the fact that when the travelling negative potential overtakes the first electrode, it becomes negative to the other electrode. Hence, a current flows from the latter to the former. Again, when the negative potential overtakes the second electrode, this becomes negative and the current through the galvanometer flows in the reverse direction. This is called *current of action*

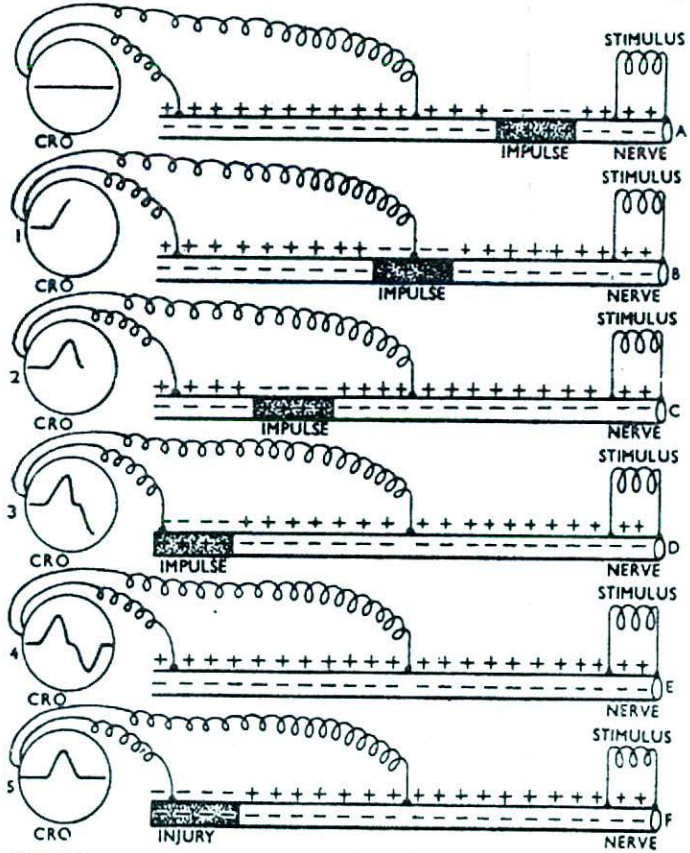


Fig.5.44.Diagrammatic representation of diphasic action potential in the cathode ray oscillograph (CRO) connecting with recording microelectrodes on the outer part of the nerve fibres. Monophasic variation in an injured nerve fibre has also been shown in F.

progressively more and more depolarisation. The depolarisation wave travels in all directions along the entire length of the nerve fibre. **This type of conduction is observed in the non-medullated nerve fibre** (FIG. 5.45).

Repolarisation wave occurs from the point of stimulus, a few ten-thousandths of a second later than the depolarisation wave and spreads progressively along the membrane, following same directions as the depolarisation has spread previously.

Saltatory conduction in the myelinated nerve fibre

In the myelinated nerve fibre, conduction depends upon a similar pattern of circular current flow. Myelin sheath is an effective insulator. Ions cannot pass through the myelin sheath, and nodes of Ranvier permeate ions to pass through it more easily. That is why the membrane at

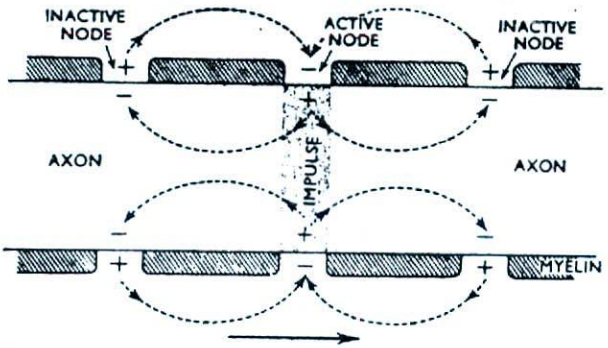


FIG. 5.46. Diagrammatic representation of local current flow around an impulse an axon in the myelinated nerve fibre (saltatory conduction) representing movements of positive charges. A straight arrow reveals direction of propagation.

nodes of Ranvier is 500 times as permeable as it is in unmyelinated fibres. For this reason the impulse is transmitted from node to node rather than continuously along the entire length of the fibre (FIG. 5.46). The depolarisation in myelinated axon jumps from one node of Ranvier to the next. This jumping or leaping of depolarisation from node to node is known as **saltatory** (*saltare* = to dance) **conduction** (FIG. 5.47).

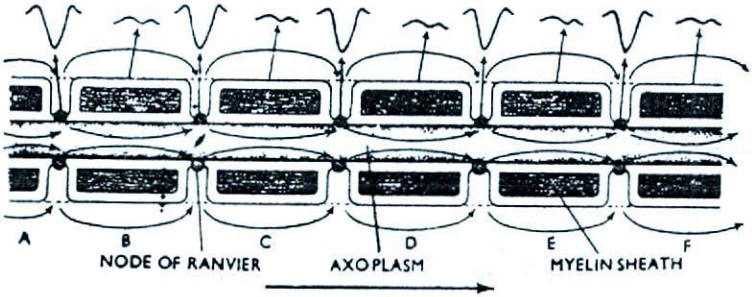


FIG. 5.47. Diagrammatic representation of the saltatory conduction along a myelinated axon. The straight arrow represents direction of propagation.

The current which remains confined to the nodes depolarises the internodal part by local circuit action. The myelin sheath increases the velocity of conduction. Huxley and Stampfli in 1949 demonstrated the following experiment.

A small medullated fibre supplying the frog's gastrocnemius muscle after being dissected out is placed on two glass slides and a moist thread forms a bridge on the slides. The slides are kept at a distance and are covered with a film of Ringer's solution. The lipid part of the nerve fibres rapidly dries up, but the nodes remain moist. The muscle contracts

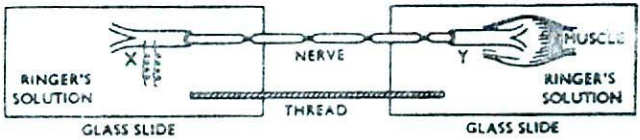


FIG. 5.48. Huxley and Stampfli's experiment to demonstrate the conduction of nerve impulse depending upon action current flowing outside the myelin sheath; X, proximal and Y, distal portion of the nerve to the muscle.

on stimulating the nerve, but if the wet thread is removed the conduction is blocked and the muscle ceases to contract. The mechanism is that when the nerve is stimulated at *X*, the action current gradually spreads to *Y* but the conduction will only take place if a return circuit reaches back to *X* (FIG.5.48). As the internode is already dry and becomes non-conductor, so the return circuit is possible due to the moist thread forming a bridge on the slides. This experiment definitely shows that although the internode is dry and non-conducting on the outside but due to the presence of moist thread, conduction takes place.

SYNAPSE

Definition. *Synapse is the junctional region where one neurone ends and the other begins.* The terminal branches of the axon (*presynaptic terminals*) of other neurones (*presynaptic cell*) come in contact with the cell body (soma) or the dendrites of another (*postsynaptic cell*). Many presynaptic neurones

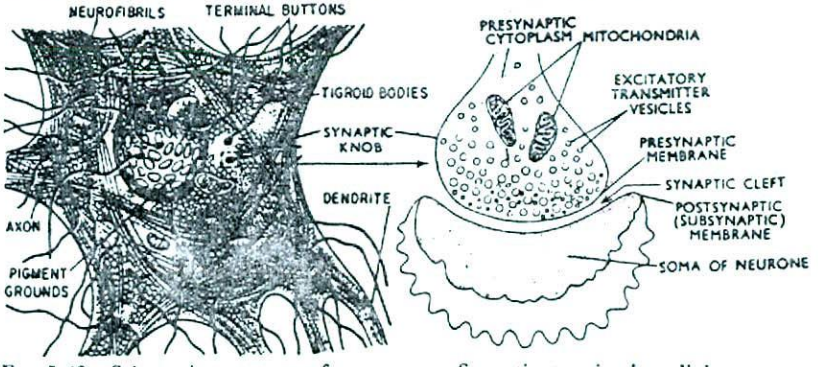


FIG. 5.49. Schematic structure of a neurone. Synaptic terminations link neurones They do not adhere to the cell surface but are separated by the intersynaptic space Within the cytoplasm of the neurone are found typical neurofibrils, mitochondria pigment granules, and tigroid bodies (*left side*). On the right side an electron microscopic structure of an axosomatic synapse.

may converge on any single postsynaptic neurones and the axon of any presynaptic neurone may divide into multiple branches and may diverge to end on multiple postsynaptic neurones.

Classification. According to the nature of connections, the synapses can be classified as such: (1) axosomatic synapse (Figs. 5.49 & 5.50B), (2) axodendritic synapse (Fig. 5.50A), and (3) axo-axonic synapse.

In **axosomatic synapses,** the presynaptic terminal of the axon ends in the cell body (soma) of the neurone. In the cerebellum synaptic connections in between the basket cell and the Purkinje cells are of axosomatic type. The axons of *basket cell* make synapses with the soma of the

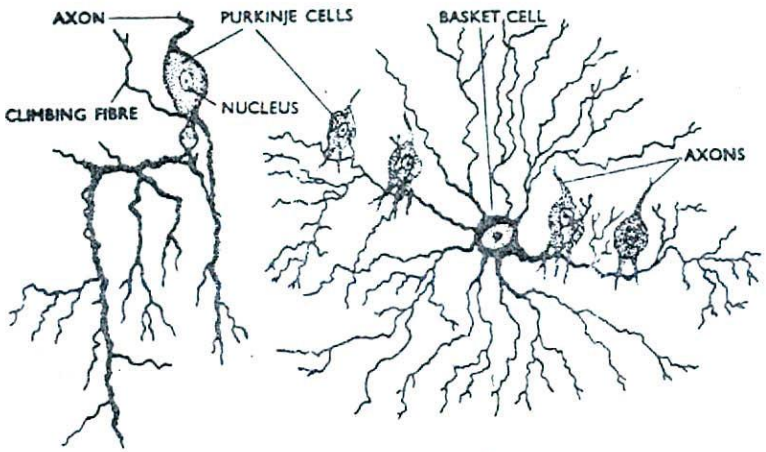


Fig. 5.50. Diagrammatic representation of almost parallel axod-pdritic synapses upon the dendrites of a Purkinje cell of the cerebellum showing climbing fibres (*left side*) and axosomatic synapses of the axon of a basket cell upon the Purkinje cells of the cerebellum (*right side*).

Purkinje cells. This type of synapse is also present in cerebral cortex where basket cell makes synapse with the soma of the pyramidal cells (Fig. 5.50B).

In **axodendritic synapse,** the presynaptic fibres of any axon end in the dendrites of the postsynaptic cell. This type of synapse is also present in cerebellum where climbing fibres form axodendritic connections with the dendrite of the Purkinje cell (Fig. 5.50A).

Axo-axonic synapse is also claimed to be present and in such synapse presynaptic fibres of any axon ends in the axon of the postsynaptic cells.

Anatomy of the synapse. Microscopic anatomy of a motor neurone of the anterior horn cells of the spinal cord shows the main body of the neurone—soma, dendrites, axon and multiple presynaptic terminals (**synaptic knobs**) ending in the soma and dendrites. These presynaptic terminals are the ends of the neurofibrils of other neurones (Fig. 5.50).

Electron microscopic structure shows that there are two types of presynaptic terminals. In one type the ends of the presynaptic terminals are enlarged to form a knob or

bouton which is known as **synaptic knob.** In another type the presynaptic terminals are wavy and having no knob at its terminals. It is claimed that knobbed type is *excitatory* whereas wavy type is *inhibitory*.



FIG. 5.51. An electron micrograph of cerebellar cortex of a cat showing tertiary dendrite (D) with spines (S) of the Purkinje cell, dilated portion of parallel fibres (F) of granular cells with synaptic vesicles (V). ×93,000.
By courtesy of Dr. C. R. Dutta, M.B.B.S., M.Sc. (Med.).

Under electron microscope it is seen that presynaptic fibres end in an expanded terminal—the *synaptic knob* (FIG. 5.51). The synaptic knob and soma—each has an intact membrane. The membrane of the synaptic

knob is known as *presynaptic membrane* and that of the soma, the *postsynaptic (subsynaptic) membrane*. The synaptic knob has got intimate contact with a portion of the membrane of the postsynaptic cell. The synaptic knobs are separated from the soma of the postsynaptic cell by a *synaptic cleft* having an average width of approximately 200 Angstroms (1 Å = mμ) (Fig. 5.52).

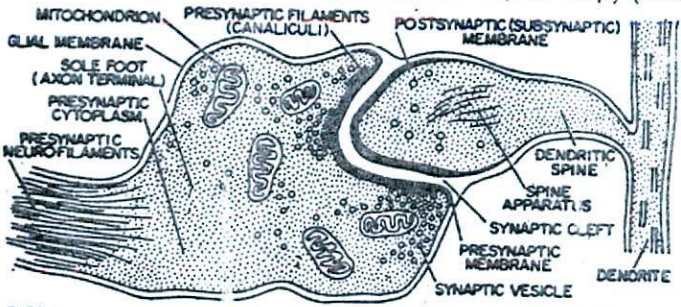


Fig. 5.52. Electron microscopic representation of highly schematic enlargement of an axodendritic synapse.

The synaptic cleft actually represents the real discontinuity of cell cytoplasm in the synaptic junction. De Robertis and others (1963) have shown in the synapse of brain cortex (central synapse) the presence of *parallel intersynaptic filaments (canaliculi)* of about 50 Angstroms crossing the synaptic cleft. These filaments are fixed at both ends with the presynaptic and subsynaptic (postsynaptic) membranes. At present the functions of these filaments are not clear. Besides these there is a web of filaments which is implanted on the subsynaptic membrane and extended for a varying and considerable distance in the postsynaptic cytoplasm. This web of filaments (canaliculi) is known as *subsynaptic web* (SSW). This subsynaptic web has been observed in the central synapses of the brain cortex and in the retinal synapses (Fig. 5.53). The synaptic knob contains mitochondria and a large number of synaptic vesicles. The *synaptic vesicles* are more concentrated towards the sites fronting the synaptic clefts. The tubular (vesicular) neuroprotofibrils and the vesicles of the endoplasmic reticulum are present

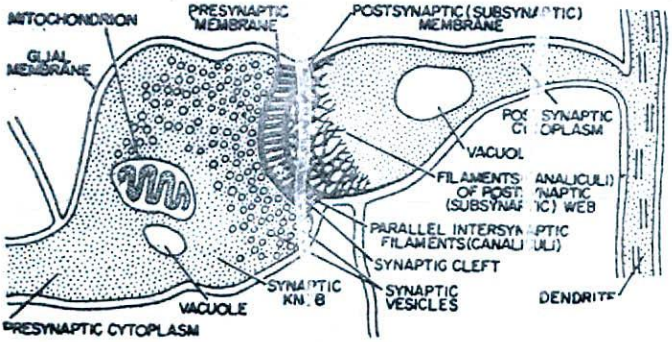


Fig. 5.53. Electron microscopic representation of highly schematic enlargement of the synapse of the brain cortex (central synapse).

but less conspicuous. The synaptic vesicles contain the excitatory transmitter materials that mediate transmission of impulses from the presynaptic neurones to the postsynaptic neurones. It is claimed that mitochondria probably take part in the synthesis of transmitter substance (Figs. 5.52 & 5.53).

Mechanism of synaptic transmission

The *transfer of information across a synaptic junction is called synaptic transmission* and these transmissions are brought about either by chemical or by electrical or by both processes. Existence of electrical transmission in mammalian is not known.

Nerve action potential (NAP) arriving at the axonal terminals, initiates a series of events, causing either a transmission of an excitatory or inhibitory in nature across the synapse or neuro-effector junctions.

The neurotransmitter substances are probably synthesised in the region of the axonal terminals and stored there in the synaptic vesicles. At rest these transmitter substances are also slowly liberated from these vesicles at a very slow amount which is incapable producing any propagated impulse. However, when the NAP reaches axon terminals, there is synchronous release of several quanta of transmitter substance. There is no proper explanation of the mechanism underlying the release of the transmitter substance from the synaptic vesicles following activation of the synaptic knobs by the propagated action potential. It is claimed that for the adequate release of transmitter substance, proper ionic concentration of extracellular Ca^{++} which may enter the extra axonal medium and in turn activate the discharge of the contents of the vesicles to the exterior.

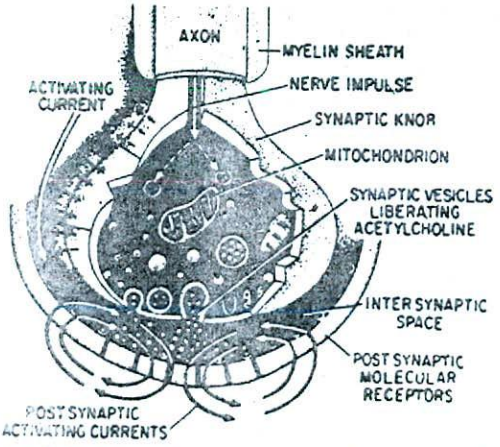


Fig. 5.54. Schematic representation of synaptic excitation. The transmission of nerve impulse is linked to a specific electrochemical process. Activating current first travels along neuronal process, afterwards radiates over the synapse and causes the liberation of acetylcholine contained in the synaptic vesicles. Acetylcholine traverses the intersynaptic space and becomes attached to molecular receptors which are situated on the postsynaptic membrane (the neuronal cytoplasm to be activated) and this causes a postsynaptic current of action in this membrane. Free acetylcholine liberated is hurriedly destroyed by the acetylcholinesterase. The mitochondrion transmits energy necessary for these processes.

Transmitter substances thus released, diffuse across a distance of 100–500 Å of the synaptic cleft and combine with the hypothetical receptor substance of the postsynaptic membrane causing increase permeability of membranes. It has been postulated that there are two types of permeability changes in the postsynaptic membrane. One is the gene-

ralised increased permeability of all types of ions causing a localised depolarisation of the membrane and excitatory postsynaptic potential. Other possibility is the selective increase in permeability of the membrane to only the smaller ions like K^+ and chloride ions, causing hyperpolarisation of the membrane, and that constitutes the inhibitory postsynaptic potential (IPSP).

If the EPSP exceeds threshold value, then it initiates the propagated NAP in the postsynaptic neurone or muscle action potential (MAP) in most skeletal and cardiac muscles.

During the development of the EPSP, simultaneously IPSP may be developed at the same site by the incoming NAP from the other sources. The propagation of nerve impulse by the EPSP is dependent upon the intensity of this postsynaptic potential. Frank and Fuortes (1957) and Eccles (1961) have described that in the CNS and also at other sites, inhibition can also result from the depolarising action of a transmitter on presynaptic inhibition.

As soon as the impulse is transmitted, the transmitter substance is immediately destroyed by the specific enzymes present in the rim of the synaptic gutter. As for example AChE (acetylcholinesterase) in the cholinergic junction (FIG.5.54).

Chemical nature of transmitter substances. Acetylcholine has been considered to be the transmitter substances of the (1) cholinergic effector organs, (2) postganglionic autonomic nerve endings, (3) preganglionic sympathetic nerve endings, (4) at some sites of the CNS, (5) neuromuscular junction.

Norepinephrine (noradrenaline) has been considered to be the neurotransmitter of the autonomic effector organs supplied by the postganglionic sympathetic fibres. Burn and Rand (1959) have claimed that in the adrenergic transmission of the sympathetic nerves, ACh plays an important role. They have described that with the stimulation of the sympathetic nerves, ACh is first liberated and this liberated ACh then causes release of norepinephrine that finally acts on the effector organs. Further work is required for substantiating this concept.

Other transmitter substances are 5-HT, γ-aminobutyric acid (GABA), large number of other amino acids such as, alanine, glycine, aspartic and glutamic acids, etc. Substance P (polypeptide) has also been considered to be transmitter substance of primary afferent fibres. This fact has not yet been substantiated.

Nature of transmission in the CNS

Cholinergic transmission. Role of acetylcholine (ACh) in the transmission of nerve impulse in the cholinoceptive synapses at the neuromuscular junction, autonomic ganglia, etc., is well-known (FIG.5.55). The presence of ACh in the CNS has been known for last four decades. Being distributed non-homogeneously it performs a specific function in some region but not in all regions. Little ACh is present in the dorsal root, the optic nerves, and the cerebellum. Brain stem, thalamic nuclei and cerebral cortex contain moderate amount, but caudate nucleus and the retina contain very large amount. Nature of distribution of true acetylcholinesterase (AChE) is roughly parallel to that of ACh. Studies with the multiple-barrelled micropipette it is observed that transmission in the recurrent

axon synapses upon Renshaw cells is cholinergic in nature and it resembles those in neuromuscular junction and in postganglionic cells in the autonomic ganglia. With studies in central neurones, it is observed that 10%

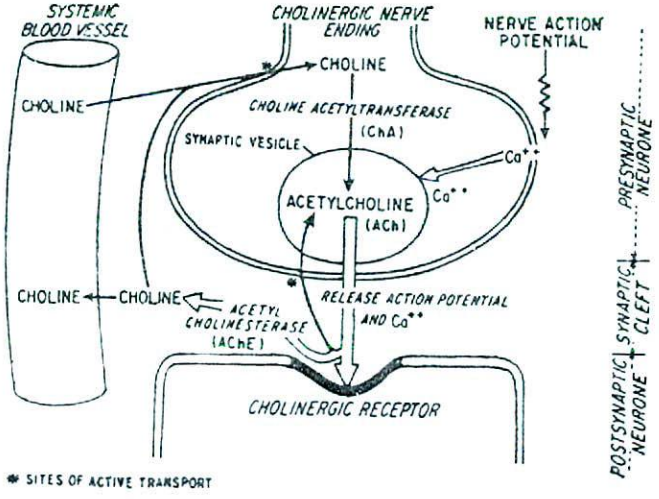


FIG. 5.55. It shows processes involved in synthesis, release and deposit of ACh at cholinergic nerve terminals and receptor site during transmission of nerve impulse.

of cortical neurones are activated by cholinergic synapses. Pseudocholinesterase is also present in various parts of the CNS.

Central adrenergic transmission. Norepinephrine is the major transmitter agent in the postganglionic sympathetic neurones. Its presence in the ganglia can be demonstrated by histofluorescent methods. Synthesis and metabolism of catecholamines have been presented in FIG. 5.56 and also *vide* chapter 4.

The presence of adrenergic substances in the extracts of the mammalian brain and also its regional distribution in the brain have been described as early as 1954 and indicated that adrenergic transmission is possible. Whole brain concentrations of catecholamines are about 0·1 to 0·5 μgm per gm. Midbrain, pons, medulla, cerebral cortex, hippocampus, cerebellum and spinal cord contain catecholamines in lower concentration. In the hypothalamus, olfactory bulb, retina, median eminence, limbic system, large amounts of amines are present. In the spinal cord, there is a system of descending adrenergic fibres which terminate about neurones of the intermediolateral horn. Central adrenergic systems have also been mapped out by following the technique of fluorescent.

Mechanisms of synthesis, storage, inactivation and removal of norepinephrine are present in the CNS and are in general similar to those in peripheral adrenergically innervated tissues. As catecholamines cannot cross the blood-brain barrier, the enzymes and precursors required for norepinephrine synthesis are present in the brain.

Dopamine, the immediate precursor of norepinephrine is also suspected to act as transmitter agent in certain motor fu[illegible]tion of the CNS.

In Parkinson's disease the dopamine metabolism is affected and the drugs that cause Parkinsonism-like state, have been shown to alter the metabolism of dopamine.

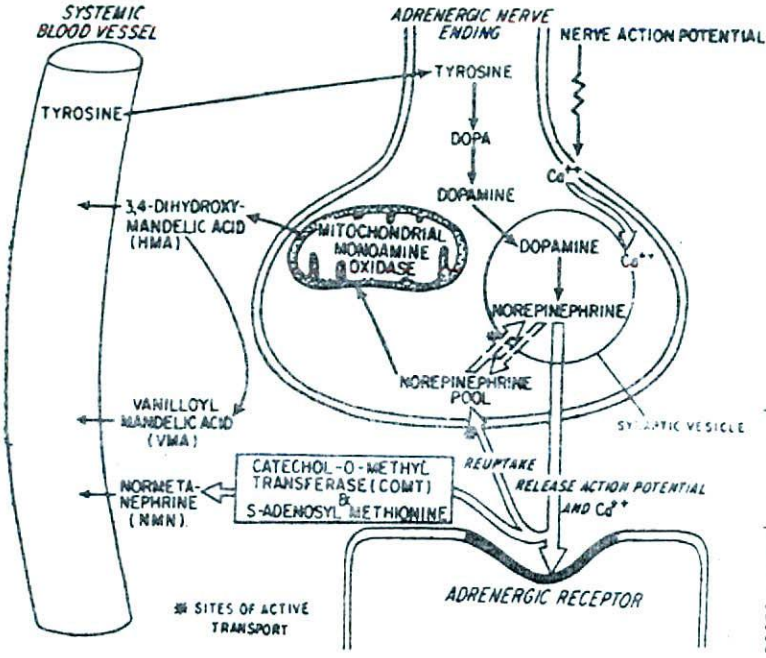


FIG. 5.56. It shows processes involved in synthesis, release and deposit of norepinephrine at the adrenergic nerve terminal and receptor site during transmission of nerve impulse.

OTHER TRANSMITTERS

(*a*) **Serotonin**—This indole has been proposed frequently as the CNS transmitter. It is distributed in regional manner and is present in higher concentration in the hypothalamus, basal ganglia and the spinal cord. Enzymes required for synthesis and breakdown are present in the brain.

(*b*) **Histamine**—This amine is also present in the highest concentration in the hypothalamus. Some histamine has also been extracted from the synaptosomal fractions of centrifuged brain homogenates. Enzymes required for synthesis and catabolism are also present in the CNS.

(*c*) **Amino acids**—(*i*) **Glutamic acid** has got some powerful excitatory effect on some central neurone but **γ-aminobutyric acid** (GABA) has got some inhibitory effects. GABA is synthesised only in the CNS from glutamic acid by a specific decarboxylase. It is present in highest concentration in colliculi, diencephalon, and occipital lobes but in lower concentration in the pons, medulla, and most of the cerebral cortex. It acts by stabilising membrane potentials at their resting value. It may decrease the excitatory activity but is apparently not a synaptic mediator. Previously it was known as mediator for postsynaptic inhibition, but it is not true and is claimed to be a presynaptic inhibitor, which requires further

clarification. Glutamic acid may depolarise neurone when placed directly on their membranes through micro-electrophoretic method. (*ii*) **Glycine** also acts as a mediator responsible for direct inhibition in the spinal cord.

(*d*) **Peptides**—Role of **substance P** (SP) in the CNS is reported over 36 years ago. It is a basic polypeptide and has got a mol. wt. of about 1600 daltons. Exact structure is not known. It is present in highest concentration in the hypothalamus, dorsal root of the spinal nerves and also comparatively in large amount in substantia nigra. This substance is associated with transmission in the sensory pathways in the spinal cord.

Fatty acid derivatives—Prostaglandins are also present in high concentration in the brain. These are also released from cerebral cortex, cerebellum and spinal cord. It is suggested that prostaglandins may take part in central synaptic transmission (*vide* chapter 4). Definite role is not known.

Sites for secretion of known and suspected transmitter agents have been presented in the following table:

Substance	*Known sites*	*Probable sites*
ACh	Myoneural junction Postganglionic parasympathetic nerve endings Postganglionic sweat gland and muscle vasodilator ending Preganglionic autonomic nerve ending	Motor and cerebral cortices Posterior gray material of spinal cord Motor nuclei of vagal and hypoglossal nerves Thalamus Caudate nucleus Mammillary bodies Supraoptic and paraventricular nuclei of hypothalamus Retina
Norepinephrine	Postganglionic sympathetic nerve ending	Hypothalamus
Dopamine		Caudate nucleus, putamen, hypothalamus, retina
Serotonin		Hypothalamus, basal ganglia and spinal cord
Substance P		Substantia nigra, hypothalamus, retina
Histamine		Hypothalamus
GABA		Spinal cord, cerebral cortex, postsynaptic junction
Prostaglandins		Spinal cord, cerebellum, cerebral cortex
Amino acids: Glutamic acid Glycine		 Central neurones Spinal cord

Excitatory and inhibitory postsynaptic potentials

Excitatory postsynaptic potential (EPSP). When an excitatory volley of impulses excites a motor neurone, depolarisation of the cell

horn (FIG. 5.58). But the Renshaw cells in turn send inhibitory impulses to these motoneurones. Due to the 'feedback' mechanism the discharge

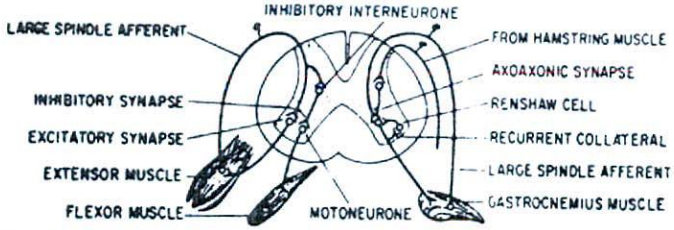


FIG. 5.58. Diagrammatic representation of the excitatory and inhibitory pathways in the spinal cord.

of impulses from the motoneurones is inhibited. It is probable that collateral endings of the motoneurone liberate acetylcholine which stimulates the Renshaw cells.

Postsynaptic inhibition. *Inhibition can be defined as an active process that either prevents the onset of activity in a structure or stops activity already present.* It may be postsynaptic or presynaptic. The postsynaptic inhibition is produced across a synapse having axosomatic connection and is due to release of an inhibitory transmitter. This inhibitory transmitter then acts on the postsynaptic membrane of the junction and inhibits it (FIG. 5.59).

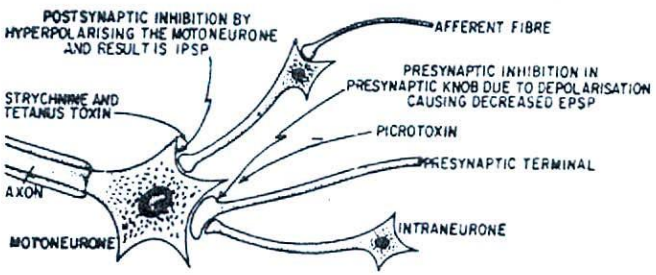


FIG. 5.59. Arrangements of central neurones that cause presynaptic and postsynaptic inhibitions.

In vertebrates this type of inhibition is present either in the CNS or in the autonomic nervous system.

Eccles (1968) has described that there are two chemically transmitting synapses on a nerve cell of which one is excitatory having axodendritic connection and other one is inhibitory having axosomatic connection (FIG. 5.60). The excitatory synapses when stimulated by the incoming afferent volley, liberate transmitter substances which open up the sodium and potassium ionic gates in the subsynaptic membrane. Depolarisation occurs causing the development of EPSP and when the EPSP attains a critical level the impulse is propagated through the axon.

But when inhibitory synapses are stimulated by an incoming afferent volley, there is release of transmitter substance which opens up chloride and/or K^+ gate causing hyperpolarisation of the postsynaptic membrane and thus the IPSP develops. So if the inhibitory synapse is stimulated sometimes earlier than the excitatory one or if these two synapses are

from the synaptic vesicles following repeated presynaptic stimulation at a faster rate.

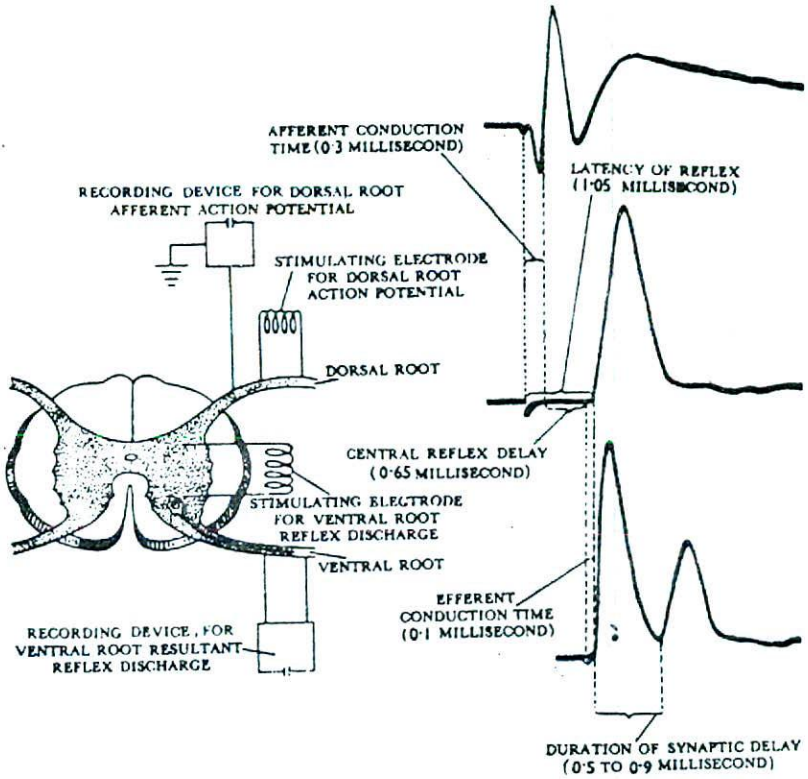


FIG. 5.57. Hypothetical demonstration of monosynaptic reflex with arrangement of stimulating electrodes and recording device (*after Renshaw*, 1940).

5. **Inhibition.** Inhibition may be defined as *an active process which either prevents the onset of activity in a structure or stops the activity already present.* It may be either postsynaptic or presynaptic and direct or indirect. Inhibitory impulse causes hyperpolarisation of the cell membrane beneath the synapse. This is known as inhibitory postsynaptic potential (IPSP). This is due to increased permeability of the cell membrane to K^+ and Cl^- caused by the liberation of an inhibitory chemical transmitter. Na^+ permeability is decreased; and efflux of K^+ and influx of Cl^- from postsynaptic terminals hyperpolarise the postsynaptic membrane. The net effect is increased negativity in the cell with increased membrane potential (−90 mV). Thus the inhibitory postsynaptic potential is developed. The inhibitory postsynaptic potential (IPSP) opposes the excitatory postsynaptic potential (EPSP).

Motoneurones while traversing the spinal cord to the anterior nerve root give off collaterals which make excitatory synaptic connections with a special group of cells called the **Renshaw cells** situated at the anterior

horn (FIG. 5.58). But the Renshaw cells in turn send inhibitory impulses to these motoneurones. Due to the 'feedback' mechanism the discharge

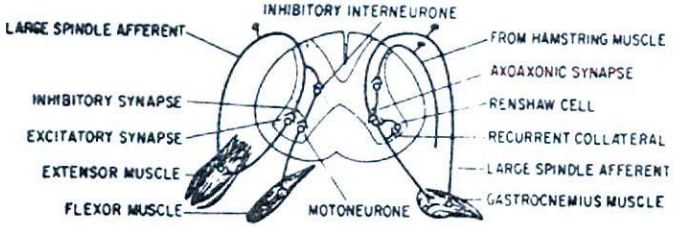


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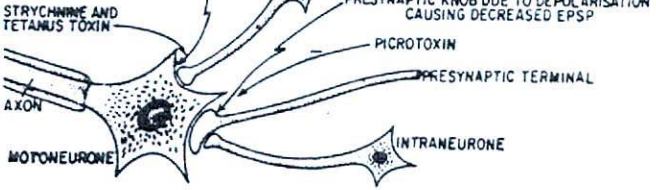


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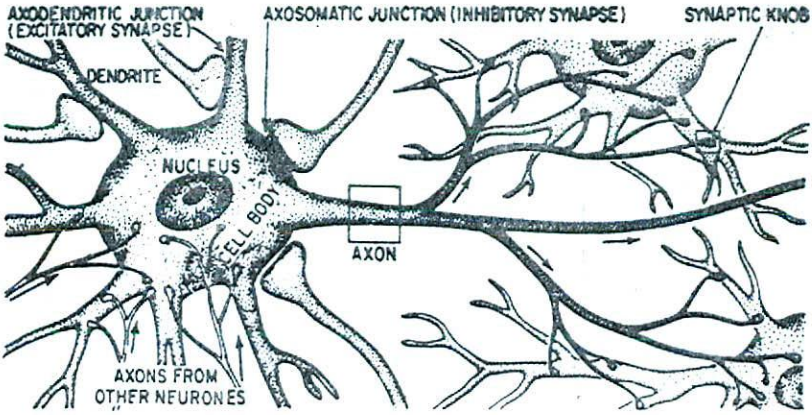


FIG. 5.60. Nature of synaptic connection in the CNS in relation to its inhibitory and excitatory states.

stimulated simultaneously then there is possibility of inhibition as the inhibitory synapse by hyperpolarisation may antagonise the depolarising action of the excitatory synapse. So the hyperpolarising effect of inhibitory synapse will prevent the generation of impulse by the excitatory synapse. Thus the excitatory postsynaptic potential developed by stimulation of an appropriate afferent nerve is depressed.

In summary, the postsynaptic inhibition is due to release of inhibitory transmitter which is capable of changing the permeability of the postsynaptic membrane to either potassium or chloride or both. This change of permeability of the membrane will cause hyperpolarisation of the postsynaptic membrane and consequently, the action potential elicited by the excitatory stimulus will fail to occur.

Nature of transmitter substance is not known yet. Acetylcholine is the inhibitory

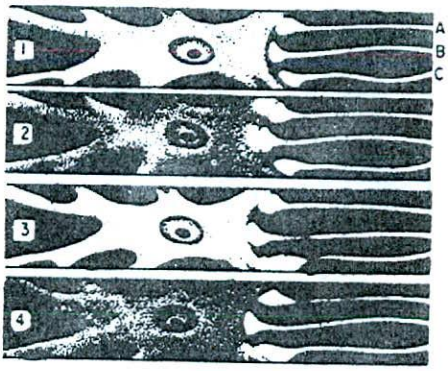


FIG. 5.61 Diagrammatic representation of structure and action of synapse. Both excitatory and inhibitory types of synaptic action exist. Two excitatory synapses (A, activated and B, not activated) and an inhibitory synapse (C, not activated). In the case of a motor nerve cell only a single excitatory impulse is not enough to cause any motor response from the cell (1). When both excitatory synapses appear to act, the response takes place (2). The inhibitory synapse should also enter into action and the threshold is not crossed, so there is not a motor response (3). In (4) the action of inhibitory synapse takes place. From an electrical point of view, there is no difference between the excitatory or inhibitory types of impulse, which travel along nerve fibres. Excitation or inhibition depends entirely on which kind of chemical agent is released by the electrical impulse. Acetylcholine is liberated by the excitatory synapses, whereas GABA is supposed to be the chemical agent with an inhibitory action.

transmitter of the vagal effector organs. In Crustacean neuromuscular junction GABA has been considered to be the inhibitory transmitter substance (FIG. 5.61).

Strychnine and tetanus toxin depress the postsynaptic inhibition. Strychnine inhibits postsynaptic inhibition by competing for receptor sites at the synapse.

Presynaptic inhibition. Primary afferent fibres and possibly the axons of several other types of neurones may be subjected to a prolonged depolarisation, exerted at or near the terminals of the axon. The presynaptic depolarisation blocks or decreases the action potential that is propagating towards the axon terminals and consequently, a reduced amount of transmitter substance is released by presynaptic action potential. This inhibitory phenomenon has been termed as presynaptic inhibition (FIG. 838). This type of inhibition was originally described by Frank and Fuortes (1957). They described that muscle afferent volleys produce an inhibition of the EPSP and reflex discharges of motoneurones, elicited by a testing volley, without any other remarkable effect upon those motoneurones and also without eliciting IPSP. Presynaptic inhibition can be recorded intracellularly from a motoneurone. But the mechanism as well as the distribution of presynaptic inhibition have been studied in detail by Eccles *et al* (1960, 1961) and also by Eccles himself (1964, 1964a). Eccles and his coworkers have observed that the presynaptic inhibition is always associated with a depolarisation of the presynaptic fibres (primary afferent depolarisation, PADP). With this finding they postulated that presynaptic depolarisation was responsible for the depression of EPSP because it reduced the size of the presynaptic impulse and hence decreased the liberation of the excitatory transmitter. They have further postulated that the depolarisation was due to the activation of an axo-axonic synapse located near the terminal of the recipient afferent fibres. They also described that this synapse was activated through the polysynaptic reflex pathways with the involvement of at least two interneurones in serial order in the central pathways. This presynaptic inhibition is not localised in the Ia afferent fibres but also extended to afferent Ib and Group II and III cutaneous afferent terminals. Devonandan *et al* (1964, 1966) have clearly demonstrated the presynaptic inhibition in cats evoked by muscle stretch and muscle contraction respectively. Presynaptic inhibition resulted from muscle contraction has been considered by them as the cause of activation of Golgi tendon organs.

Besides this, presynaptic inhibition exerts a powerful action on all types of large afferent fibres entering the spinal cord. Presynaptic inhibition is exerted both on to those Ia terminals making monosynaptic excitatory contacts on motoneurones and on to those conveying excitation to neurones of ascending tracts.

Presynaptic inhibition can be demonstrated by eliciting a monosynaptic EPSP of either extensor or flexor motoneurone and if it is preceded by volleys from any dorsal root. Ipsilateral flexor components of Group Ib and Ia fibres are more effective in causing the inhibition. This inhibition may endure as long as 200–300 msec. and is extremely resistant to strychnine. Strychnine and tetanus toxin depress the postsynaptic inhibition. Picrotoxin, another convulsive drug, depresses the presynaptic inhibition.

Frank and Fuortes (1957) reported that the monosynaptic EPSP which was evoked in a motoneurone by a volley in its muscle nerve was sometimes reduced in size by a conditioning volley in another muscle nerve.

Eccles and coworkers correlated the time course of this EPSP depression with the dorsal root potentials, which are evoked under similar experimental condition and concluded that 'presynaptic inhibition' was responsible for both phenomena. The depolarisation of the excitatory presynaptic terminals by axo-axonal synapse was postulated to decrease the amplitude of the action potential propagated into these terminals and thereby to diminish the amount of excitatory transmitter substance liberated.

6. **Convergence and divergence of nerve impulses.** Since the axons of many neurones can form a common synapse with the next neurone, a number of nerve impulses from various sources may converge on to a single nerve cell and may be transmitted through it. Convergence of impulses occurs into the final common path, e.g., convergence of afferent impulses to the anterior horn cells. Similarly there is also some divergence of impulses (on the afferent side), e.g., divergence of visual impulses from the retina to the occipital cortex.

7. **Synaptic block.** The inhibitory transmitter may be blocked at the synaptic junction. *Strychnine* blocks the inhibitory activity and causes reduction or abolition of inhibitory postsynaptic potential (IPSP) in most of the synaptic junctions. *Tetanus toxin* also has got similar effects. Both strychnine and tetanus toxin produce convulsion by blocking the inhibitory transmitter mechanism.

8. **Summation.** Vide *General characteristics of reflex action.*

9. **Occlusion.** Vide *General characteristics of reflex action.*

10. **Ephaptic transmission.** 'Ephapse' means false synapse. Ephaptic transmission is the process of transmission of an electrical impulse from one axon to another without having any synaptic connection (i.e., false synapse). If one nerve fibre falls on the other fibre then threshold stimulation of the one fibre will cause excitation of the other by the propagation of impulse through the ephapse (false synapse) (Fig. 5.62).

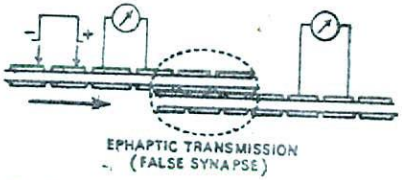


Fig. 5.62. It showing ephaptic transmission. Arrow represents direction of propagation.

This was first observed by Hering (1882). Calcium lack stimulates the excitability of the ephaptic region.

Myoneural junction

Anatomical consideration (Figs. 5.63 & 5.64). The motor nerve before ending into the muscle fibre loses its myelin sheath. The nerve fibre, at its termination, branches into several expanded complicated structures which are known as axon terminals or sole feet.

Under light microscope (Fig. 5.64) the myoneural junction shows naked motor nerve endings with the Schwann cells. The expanded nerve endings or sole feet lie within the corrugated sarcolemma—the junctional

folds of the muscle fibre. The corrugated sarcolemma is formed by the numerous invaginations of the sarcoplasm. These sarcolemmal invaginations are collectively called *synaptic gutter*. The sole feet do not end within

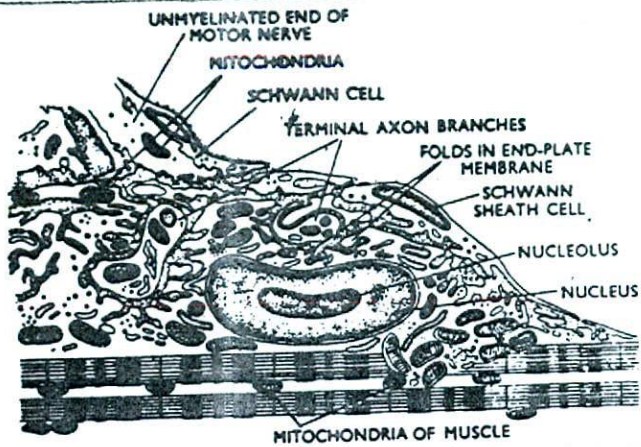


FIG.5.63. Diagrammatic representation of an electron microscopic structure of the neuromuscular junction.

the sarcoplasm but a gap is present in between the axon membrane and the sarcolemma. This gap is known as *synaptic cleft*. Synaptic cleft is filled with extracellular fluid (*gap substance*). Numerous muscle nuclei are

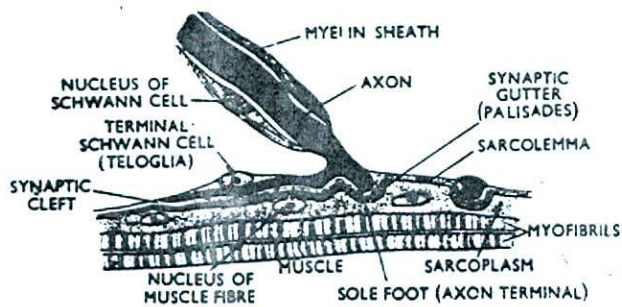


FIG.5.64. Diagrammatic representation of the relationship of nerve ending to the muscle fibres (*neuromuscular junction*).

also seen in the sarcoplasm. Under electron microscope (FIG.5.65) the sole feet show the presence of mitochondria, numerous vesicles, smaller granular elements and also endoplasmic reticulum. The whole sole foot is covered by the cytoplasm of the Schwann cell. It is claimed that mitochondria present in the axoplasm take part in the synthesis of acetylcholine—the excitatory transmitter substance of neuromuscular junction. This substance is stored in the vesicle and released when the propagated impulse reaches the postjunctional membrane (PJM). Due to presence of multiple folds in the sarcolemma, the total surface area at which the

transmitter substance acts, is increased. Choline esterase is present in the rim of the synaptic gutter. Mitochondria are also present in the sarcoplasm.

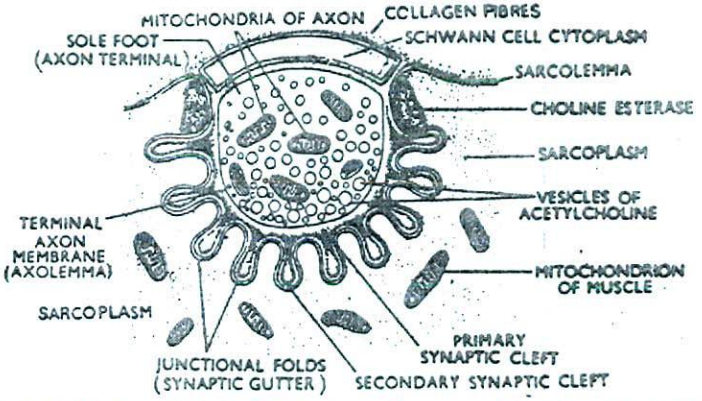


FIG. 5.65. Electron microscopic appearance of myoneural junction at the region of an axon terminal (sole foot) ending in the motor end-plate.

Mechanism of neuromuscular transmission. When a nerve impulse reaches the nerve terminals (the sole feet), depolarisation in nerve terminal takes place with the liberation of acetylcholine from the vesicles. It is claimed that for the liberation of acetylcholine from the vesicle the participation of Ca^{++} is required. By the propagated impulse, Ca^{++} from the extracellular fluid enters into the vesicles of sole feet and causes the acetylcholine to come out from the vesicles. The acetylcholine thus liberated, diffuses across the synaptic cleft and reacts with a receptor of the postjunctional membrane (PJM) forming the acetylcholine-receptor-complex. The acetylcholine-receptor-complex increases the permeability of the PJM to Na^+ and K^+. It has been described by Fatt and Katz that due to enough release of acetylcholine, a large number of pores in the PJM are developed and this state facilitates the Na^+ entry producing depolarisation of the membrane. If the depolarisation potential attains a threshold level then an impulse is propagated in both directions of the sarcolemma. Released acetylcholine is rapidly destroyed either by choline esterase which is present in high concentration in the rim of synaptic gutter or by simple diffusion. From the sarcolemma the action potential is propagated through the triad system (*vide* volume I) into the contractile units of the muscle, causing excitation-contraction coupling with the development of muscle tension. Sequential changes in neuromuscular transmission can be presented schematically.

Propagated action potential → depolarises the neurone terminals → ACh released from synaptic vesicles with the help of Ca^{++} → released ACh diffuses across the synaptic cleft ⇌ ACh forms a transmitter-receptor-complex with receptor substance of the PJM → increased permeability of Na^+ and K^+ of the PJM → depolarisation of the PJM → initiation of propagated muscle action potential in the sarcolemma → transmission of such action potential from sarcolemma to the contractile units of muscle through triad → excitation-contraction coupling → development of muscle tension.

End-plate potential. It can be defined as the potential changes in the neighbourhood of the end-plate region induced by activation of the acetylcholine-receptors which cause the increase in end-plate permeability to Na^+ and K^+.

End-plate potential can be recorded by inserting microelectrode into the motor end-plate. When an impulse reaches the neuromuscular junction, acetylcholine is liberated in the terminal nerve endings and then depolarises the muscle membrane. When this local depolarisation exceeds −30 mV to −40 mV, the spike potential in the muscle is initiated with an amplitude of +35 mV and the muscle contracts.

Spontaneous miniature end-plate potential. End-plate potentials of appreciable voltage as described above are obtained following excitation of a motor nerve fibre. But in normal muscle fibre, if microelectrodes are inserted into the motor end-plate then certain type of spontaneous electrical activity is detected though the nerve is in resting state. These random spontaneous series of disturbances with low peaked amplitude of smaller waves are called *miniature end-plate potential*. These end-plate potentials are developed due to leakage of a little acetylcholine from vesicles even in resting state. The voltage is not more than 0·5 mV.

Actions of drugs on neuromuscular transmission. Neuromuscular transmission can be blocked by two ways:

(1) by inhibiting the release of acetylcholine;

(2) by inhibiting the action of acetylcholine on motor end-plate through (*a*) competitive inhibition and (*b*) depolarisation.

Botulinus toxin blocks the neuromuscular transmissions by inhibiting the release of acetylcholine.

Curare blocks the transmissions by competitive inhibitions. It competes the action of acetylcholine on the motor end-plate. It does not prevent release of acetylcholine but inhibits its action by acting previously with the motor end-plate. *Tubocurarine* also acts competitively with acetylcholine on the motor end-plate and prevents acetylcholine from exerting its full stimulant activity.

The drugs which block the transmissions on depolarisation are—*decamethonium* and *succinylcholine*. These drugs like acetylcholine depolarise the motor end-plate and the duration of depolarisation is prolonged. The paralysis of the muscle is due to persistent depolarisation as the elimination of the above drugs are very slow. But in case of acetylcholine, the elimination is very quick as the choline esterase present in the synaptic gutter destroys it.

SYNOPSIS OF THE NEUROPHYSIOLOGICAL MECHANISM

This mechanism involves reception of stimulus by the receptor organ, transmission of the impulse from one neurone to another and transfer of the impulse through the motor end-plate to the muscle.

Let the Pacinian corpuscle (FIGS. 5.68 & 5.74B) be the receptor which is lamellated like *onion* with naked axis cylinder of the sensory nerve arborising in the central core responds to changes in pressure.

When a stimulus is applied to corpuscle it gets deformed and the mechanical stimulus is transformed into electrochemical signal which is conducted along the sensory nerve fibre. The membrane of the outer side of the axis cylinder within the receptor contains abundance of sodium and chloride ions, whereas there is predominance of potassium ion inside

the axoplasm. Under resting-condition the outer side of the membrane is *positive* and the inner side is *negative*. When the lamella is deformed it causes ionic movement across the membrane of the axis cylinder which has got specific permeability. There is at first inward flow of sodium and chloride ions which is followed by the outward flow of potassium ion. Due to these ionic movements slight depolarisation of the membrane occurs. This is known as *generator potential*. This again depolarises the adjacent axon membrane. When the stimulus is adequate, the depolarisation reaches the *threshold level* and the depolarisation spreads at the first node of Ranvier. This is *action potential*. It is generated at the first node of Ranvier and then there is *saltatory conduction*, i.e., it is conducted in 'jumps' or 'leaps' at each successive node along the sensory nerve. At the node of Ranvier there is major inward and outward flow of ions along with electrical currents. The current which remains confined to the nodes depolarises the internodal part by the local circuit action. This action potential lasts for a very short time, i.e., 1 millisecond. The action potential follows each other very quickly along the sensory nerve. The *refractory period* of the nerve is also 1 millisecond. So there is the saltatory conduction of the impulse into the gray matter of the spinal cord through the sensory neurone and is transmitted to the motoneurone of the anterior horn. At the synaptic junction in the spinal cord the axon terminals make an intimate contact with the membrane of the motoneurone. The presynaptic and postsynaptic membranes form the synapse. *The synapse acts as a functional unit of the transmission of impulses.* At the membranes there is predominance of sodium and chloride ions on the outer side, whereas potassium ion on the inner side. Due to this ionic distribution there is difference of potentials across the synaptic membranes. The small synaptic vesicles are also activated and there is *liberation of acetylcholine*. The permeability of the postsynaptic membrane is increased and there is ionic movement along with the small electrical current. Due to these changes excitatory postsynaptic potential (EPSP) develops. Then the impulse is propagated to the anterior horn cell. Under normal condition the impulses may be *excitatory* or *inhibitory*. When there is preponderance of excitatory stimulation over the inhibitory stimulation there will be *depolarisation* of the motoneurone membrane and the discharge of the action potential. When there is predominance of inhibitory stimulation over the excitatory stimulation there will be *hyperpolarisation* of the motoneurone membrane. The inhibitory postsynaptic potential (IPSP) will develop and will inhibit the discharge of any impulses.

When the motoneurone is excited, the impulse is transmitted to the *motor end-plate*. The postjunctional membrane and the axon are quite separate and remain at a slight distance. When the motor end-plate is excited, it gets depolarised. There is inflow and outflow of ions. *Acetylcholine* plays an important part in this process. End-plate potential (EPP) develops. The membrane of the muscle fibre is subsequently depolarised to the *threshold level* and the action potential in the muscle is produced. Subsequently the contraction of the myofibrils occurs.

Reaction of degeneration

By noting the electrical response of a muscle it is possible to know whether it is degenerating or not. The spot where the muscle receives its motor nerve is known as the **motor point.** These points have been

mapped out for all skeletal muscles and during actual procedure reference is made to these maps. The active electrode (**stigmatic electrode**) is placed upon the motor point of the muscle and the other passive electrode (generally large and flat) is placed on a distant indifferent spot, such as the back of the neck. By reversing the current with a commutator, the stigmatic electrode may be either made *anode* or *cathode*. With such arrangements, four sets of reactions are seen. When the stimulating electrode is cathode the response at 'make' is called *cathode-closing contraction* (C.C.C.). The response at 'break' is known as *cathode-opening contraction* (C.O.C). When the stimulating electrode is anode similar two contractions are obtained and are known respectively as *anode-opening contraction* (A.O.C.) and *anode-closing contraction* (A.C.C.). The quantitative relation is as follows : **C.C.C.> A.C.C. > A.O.C. > C.O.C.** When the muscle degenerates (1) A.C.C. becomes greater than C.C.C.; (2) no response is obtained to Faradic stimulation ; muscle starts responding to galvanic stimulation because the chronaxie is increased and excitability of the degenerating muscle is decresed and (3) a slow worm-like contraction to galvanic stimulation. This is called *reaction of degeneration* (R.D.).

EFFECTS OF NERVE SELECTION

(Degeneration and regeneration of the nerve fibre)

After complete transection of the nerve, the peripheral parts of the axons undergo certain degenerative changes which are often called **Wallerian degeneration** (as described first by Waller in 1862).

Degeneration takes place at three leves : (1) **in the nerve cell ; (2) in the proximal part of the cut fibre ; (3) in the distal part of the cut fibre** (Wallerian degeneration).

Regeneration may take place under favourable conditions. Both the processes are briefly described below.

In the nerve cell

Degeneration (Fig. 5.66C). Change occuring in the proximal part of the axons and also the cell bodies following section of an axon is known as **retrograde degeneration.** The changes in the cell bodies are :

1. **Chromatolysis.** Nissl granules disappear. It starts within 48 hours and becomes maximum by 15-20 days.
2. **Golgi apparatus,** mitochondria and neurofibrils break up and disappear.
3. **The cell draws in more fluid,** swells up and becomes rounded.
4. **The nucleus is pushed to the periphery** In severe cases it may be *totally extruded,* in which case, the nerve cell completely dies and disappears. The degree of damage and chromoto lysis depend on ; (1) *The distance of lesions from the nerve cell — Lesser the distance greater will be.*

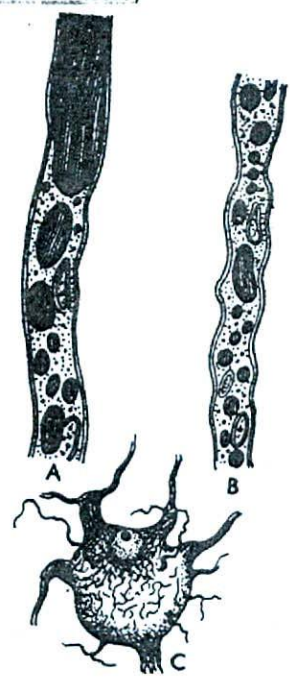


FIG. 845. Degeneration of the nerve fibres.
A & B=showing myelin droplets as degeneration proceeds.
C=cell undergoing chromatolysis, nucleus has become eccentric.

the damage. (2) *Nature of section*—If it is a sharp cut, the effects will be less. But if forcibly torn, the damage is severe and often the cell dies.

Regeneration. Regeneration in the cell bodies of thalamic neurones is not possible because the retrograde degeneration is irreversible and phagocyte cells remove the perikaryon from these dead cells. But the retrograde degeneration in the spinal motoneurone is reversible and can be regenerated and the cell bodies eventually get back all of its morphological characteristics including its functional properties. The cell regains its normal shape and size, and the nucleus returns to its original central position.

In the proximal part of the cut fibre

Since this part remains connected with the mother cell, degeneration cannot be complete unless the nerve cell dies. Ordinarily, degeneration proceeds centrally as far as up to the first node of Ranvier and in most cases degenerative changes may extend up to a few internodes when regenerative changes are initiated from the end of the *central stump*. In more severe cases, it may proceed a little higher. The nature of this degeneration and the subsequent regeneration is same as in the *distal stump or part* (*vide* below). Regeneration takes place if the neurone survives.

In the distal part of the cut fibre

Degeneration. Since this part is totally separated from the mother cell, it degenerates completely. Degeneration starts simultaneously in the whole length of the fibre up to its terminal arborisations within 24 hours and is completed by 3 weeks. Following degenerative changes are seen (FIGS. 5.66A & B and 5.67A & B):

Histological changes. 1. The neurofibrils swell, become

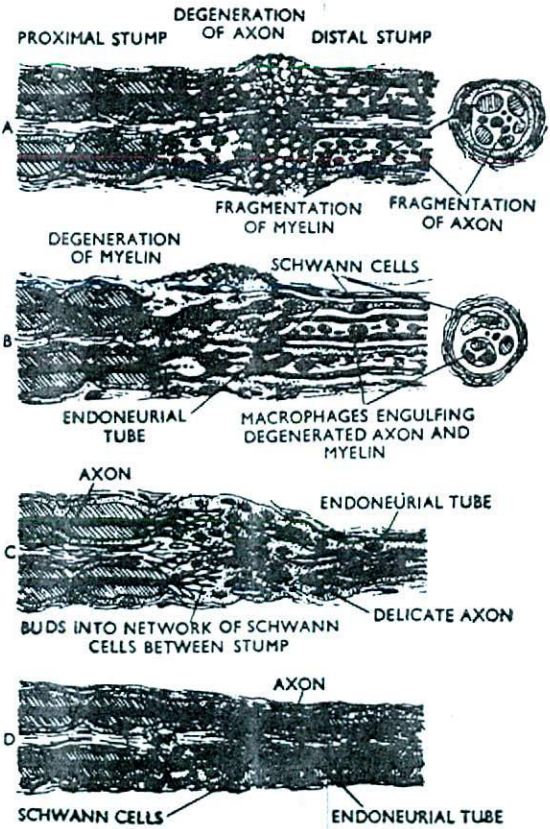


FIG. 5.67. Diagrammatic representation of the degeneration and regeneration of severed peripheral nerve fibres. A & B showing the process of degeneration and C & D depicting the process of regeneration of the nerve fibres.

tortuous and ultimately disappear and the axis cylinder breaks up into short lengths.

2. The myelin sheath disintegrates into droplets of fat. Lecithin splits up into glycerol, phosphoric acid, fatty acid and choline. They are partly removed by macrophages and partly washed out in the blood stream. If the damage be inside the central nervous system, no further change takes place.

But if it be in the peripheral nervous system the neurolemma shows the following changes:

3. The nuclei of Schwann cell multiply mitotically and the Schwann cell cytoplasm increases in amount. It starts 4–9 days after section. The macrophages penetrate the neurolemmal tubes and remove the debris (FIG. 5.67B). The Schwann tissue gradually fills up the whole tube and the process is completed by three months. From the cut distal end, the proliferating Schwann tissue spreads upwards toward the central cut end and in this way may bridge up a considerable gap (even up to 3 cm) between the two cut ends. The rate of progress of this growth is 1–2 mm per day. The peripheral neurolemmal tube shrinks to half its original diameter in 7 weeks and may remain so for about 18 months. The above degenerative changes in distal cut end of the nerve fibres were first observed by Waller and according to him it is known as Wallerian degeneration.

Regeneration. *Regeneration takes place only outside the central nervous system where neurolemma is present. Presence of neurolemma is, therefore, essential for the process. Hence in the central nervous system, neurolemma being absent, nerve fibres do not regenerate at all.* The following steps are seen during regeneration:

1. The axis cylinder grows out from the central cut end as a rounded sprout and proceeds towards the solid neurolemmal cord. The proliferated Schwann tissue in the peripheral cut end and its prolongation towards the central cut end provide an influence (Neurotropism) which guides the approaching axis cylinder. Each growing fibre splits up into numerous neurofibrils (even up to 100), the Schwann cells disappear and the fibrils enter the newly-made neurolemmal tubes (2–3 weeks after the section, the inner walls of the tube may contain a number of fibrils) (FIG. 5.67C & D). All the fibrils degenerate, excepting a single one, which gradually enlarges and occupies the central part of the whole length of the tube proceeding peripherally The daily rate of growth is about 0·25 mm in the scar tissue between the two cut ends and 3–4 mm in the peripheral neurolemmal tubes.

2. Myelin sheath begins to appear in about 15 days and proceeds peripherally along the fibre at a slower rate than the growing axis cylinder.

3. Increase in the diameter of the fibre takes place very slowly. The diameter of the fibre is limited by the size of the neurolemmal tube and that of the parent nerve cell.

With a clean sharp wound and the cut ends being in apposition, some degree of recovery usually takes place in 6–24 months. For a motor nerve, recovery may be complete. But for a mixed nerve, it is rarely so.

In the regenerated fibres the axis cylinder and myelin sheath are reduced in thickness, the internodal distance is also diminished. But the rate of conduction of nerve impulses in the regenerated fibres remains the same.

Degeneration and regeneration of the nerve endings. The framework of both sensory and motor endings can resist degeneration for months. If the nerve fibres fail to regenerate, the endings also atrophy. But if the fibres regenerate, the living frameworks of the nerve endings quickly establish connection with the growing fibres and start functioning. Some of the newly growing fibres may establish connection with new types of endings in new situations. It is also possible that some growing nerve fibres may reach a place where there was no nerve ending at all and absolutely fresh nerve endings may develop around them. Complete functional regeneration occurs after histological regeneration—3 weeks in case of motor nerve fibres and 5 weeks in case of sensory nerve fibres.

Transneuronal degeneration

When a neurone or its motor fibre degenerates, the neurone next in the chain is often found to degenerate also. This takes place in spite of the fact that there is no anatomical continuity through the synapses. *It is probably an example of disuse atrophy.* In many conditions, this type of degeneration occurs, e.g., (1) After section of the optic nerve, the cells in the lateral geniculate body degenerate. (2) After section of the posterior spinal root, the posterior horn cells degenerate. (3) In lesions of the motor cortex or pyramidal tracts, the anterior horn cells may degenerate. This type of degeneration may be the underlying cause of the so-called System diseases, viz., Amyotorphic lateral sclerosis, etc., where degeneration of anterior horn cells follows that of the pyramidal tracts.

NERVE ENDINGS

Definition *Nerve endings are the terminal bodies where the nerve fibres end in the periphery.*

Histology (Fig. 5.64). *Histologically*, there are two fundamental types of endings: (1) **Free terminals**—Here, the nerve fibres end as naked twigs of axis cylinder, without any special covering. (2) **Connective tissue body**—Here, the nerve fibre ends inside a special connective tissue body. All such bodies are built up on the same histological plan. *There are three common features: (a)* A capsule made up of layers of connective tissues, *(b)* inside the capsule, there is a core of soft cellular material, and *(c)* inside the core, ends the naked axis cylinder, either as a single process or by various forms of arborisations. While terminating, at first the neurolemma and then the myelin sheath become completely blended with the lamellated connective tissue body and lastly the axis cylinder ends in the core as a naked process (same as it began). All the end organs having a connective tissue body have got this common plan. They differ from one another by the complexity of the capsule and the mode of termination of the axis cylinder.

Functions. *Functionally*, the nerve endings may be (1) **motor** or (2) **sensory.** The **motor endings** transmit the motor impulses to the muscles. It is probable that some chemical substance, such as acetylcholine, is liberated at the endings and sets in the chemical changes underlying contraction of muscles (*vide* p. 5·55). The **sensory endings** receive the afferent sensation, hence also called the **sensory receptors.**

Receptors

Sensory receptors are a specialised structure that can be stimulated by environmental changes as well as by changes within the body. It can be defined as the terminal **afferent endings** that undergo depolarisation in response to specific type of physical stimuli. These receptors are capable of transforming different types of energy into nerve impulses that travel through sensory nerve fibres toward the central nervous system. Their functions are generally specific, one type carrying one kind of sensory impulse, such as of *touch, heat, cold,* etc. For this reason they are also known as the *peripheral analysers.* Sensation occurs only when the impulses, carried

through the sensory nerves are decoded and analysed. They are of various types—differing in structure and functions. The receptors may be classified in three ways: (*a*) in terms of their morphological entity, (*b*) in terms of the properties of the external stimuli to which they respond and (*c*) in terms of functions which they subserve.

There are different types of receptors in the body and as there is no conventional method, it has been classified in different ways. For the sake of convenience, the sensory receptors have been classified broadly into two: (*i*) **general sensory receptors**, subserving cutaneous, deep and visceral sensations, and (*ii*) **special sensory receptors** subserving different special functions like carrying

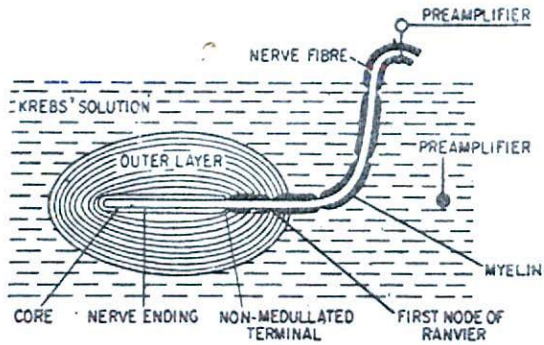


FIG. 5.68. It demonstrates the method of recording generator potential and action potential from isolated Pacinian corpuscle which is bathed in Krebs' solution. For recording one electrode is placed on the axon and the other electrode is placed on the surrounding fluid—the Krebs' solution. Active stimulus is mechanical pressure (*after Mountcastle*).

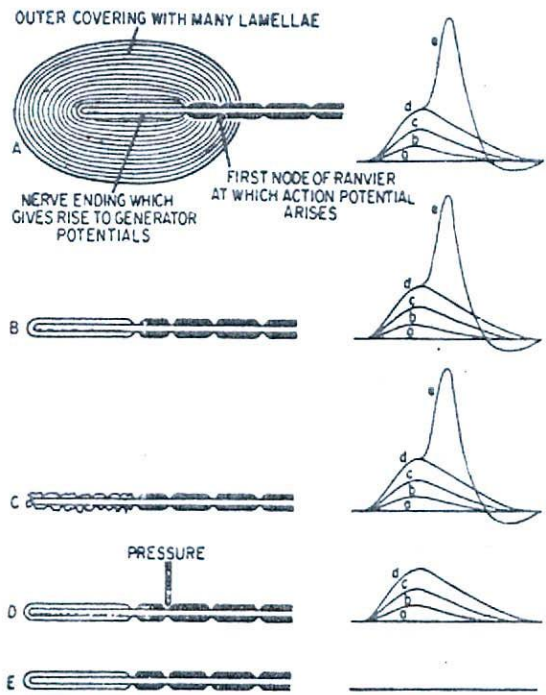


FIG. 5.69. This demonstrates the site of origin of generator potential and also demonstrates the mechanism of development of action potential. Recording method as in FIG. 5.68. A = It shows development of generator potential in graded pattern (*a*, *b*, *c*, *d*) as the stimulus strength is gradually increased with the development of propagated action potential (*e*) in a lamellated Pacinian corpuscle. B = It shows development of same generator potential (*a*, *b*, *c*, *d*) as well as action potential (*e*) though the concentric lamellae of the corpuscle are removed. C = Development of same generator potential (*a*, *b*, *c*, *d*) and action potential (*e*) though the inner core is partially removed in an unlamellated corpuscle. D = Generator potentials (*a*, *b*, *c*, *d*) as usual are developed, but action potential (*e*) is not developed after blocking the first node of Ranvier by pressure. E demonstrates failure of development of generator or action potential after degeneration of axon (*after Loewenstein*).

sensations for hearing, vision, taste, smell, etc. These have been presented systematically in page 5-67.

Receptor as a biological transducer

Transducer is a structure which transforms one kind of energy into another. Receptors behave like transducer and transmits any type of physical energy into an electrical energy, the intensity being coded by amplitude modulation. The receptor is capable of transforming local, graded and non-propagated electrical energy into non-graded, all-or-none and propagated electrical response.

Initiation of impulse in sensory receptors: Concepts of generator potential and action potential. If a receptor is stimulated, then electrical activity originating at the nerve endings can be recorded. The initial electrical activity which is stationary, non-propagated but graded is called **generator potential** or **receptor potential** (FIG.5.68). The generator potential is localised in this region without being propagated actively over the rest of the sensory nerve fibre. It has got no refractory period and is not affected by local anaesthetics, like procaine, which usually blocks the conduction along the nerve fibre. **Generator potential is not the synonym of action potential.** Action potential follows all-or-none law, is propagatory and non-graded. Action potential is developed only when the generator potential attains a threshold level due to graded activity (FIG. 5.69). When the magnitude of the generator potential is about 10 mV, an action potential is generated in the sensory nerve. If the intensity of stimulus in the receptor is further increased then the generator potential is increased further and the frequency of discharge of action potential is increased. Frequency of discharge of action potential is proportional to the magnitude of the applied stimuli.

Source of generator potential

This has been studied very successfully in the eye of horse-shoe crab and in some vertebral mechano-receptors—the frog's spindle and the Pacinian corpuscle of the cat. Pacinian corpuscle has been studied in detail as because the receptor is relatively large and can be isolated, studied with microelectrodes and subjected to microdissection. These corpuscles are surrounded by concentric lamellae of connective tissues and consist of straight, unmyelinated ending of sensory nerve fibre of 2 μ m in diameter. The myelin of the sensory nerve begins inside the corpuscle.

It has been shown by microdissection techniques that after removal of the connective tissue lamellae, there is still initiation of generator potential, along with propagated action potential. If bits of inner core of the corpuscle is removed, still there is no defect in the initiation of generator potential and subsequently the action potential is initiated. But if the first node of Ranvier is blocked with pressure or narcotics, then generator potential persists as usual but action potential is absent. If the unmyelinated nerve terminal is allowed to degenerate following section of the sensory nerve several days earlier, then no generator potential is developed. From all these experiments it is clear that generator potential is developed in the unmyelinated nerve terminal and not in the elements of corpuscle as because majority of the latter can be removed without affecting the development of generator potential. The generator potential is local to the nerve terminal and results from a process taking place there while the conducted action potential to which it normally leads is set up in the

membrane of the first node of Ranvier. Thus a generator potential is, in short, a depolarisation of the sensory nerve endings, which, if attains a certain magnitude, then may stimulate the sensory nerve fibre itself. There is a definite relationship in between the magnitude of generator potential and the frequency of discharge of the action potential.

Mechanism of initiation of generator potential

Biophysical principle underlying the process of initiation of generator potential is not clear. It is known that due to stimulation of the receptor, there are increase of Na^+ conductance, inward rush of Na^+ through the membrane of the unmyelinated terminal. The resultant influx of Na^+ causes the development of generator potential. The magnitude of the permeability change is proportional to the intensity of the stimulus (Fig. 5.70). The importance of Na^+ in the generation of generator potential has been observed in Pacinian corpuscle by Gray and his colleagues. Na^+ depletion

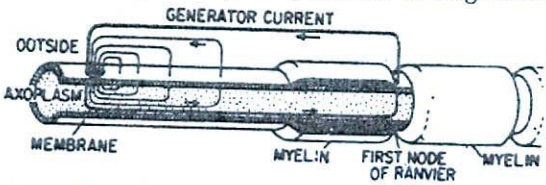


FIG. 5.70. It shows the local change in membrane permeability and resulting flow of generator current reaching the first node of Ranvier (*after Loewenstein*).

diminishes the generator potential in Pacinian corpuscles. Perfusion with Na^+ free solution but made isotonic with choline chloride or sucrose does not abolish the generator potential but only reduces it to about 10% of the control value. It thus indicates that generator potential is initiated by permeability to Na^+ and also to other ions as well. Thus the sequences of events that take place in the initiation of generator potential and subsequently the action potential in a receptor are as follows :

Stimulus → local change in permeability of Na^+ ions and probably other ions → local depolarisation → initiation of local, non-propagated and graded potential → generator potential → attaining the threshold level → action potential (all-or-none and propagated).

Properties of receptors

1. **Differential sensitivity** : Each receptor is sensitive to a specific stimulus. The receptor is designed for this stimulus and does not respond to other types of stimuli in normal strength. This specific stimulus is called as the adequate stimulus for that receptor organ.

2. **Relation with strength of stimulus.** As strength increases, the frequency of discharge rises and sensation becomes more intense.

3. (Muller's law of specific nerve energies.) Each receptor organ with its afferent nerve transmits only one modality of sensation. Generally action potentials in all nerve fibres are similar, yet action potential developed from a pressure receptor, causes a sensation of pressure not of warmth or cold. This is under the purview of the **doctrine of specific nerve energies.** The sensation perceived due to impulses generated in a receptor depends upon the sepcific part of the brain they ultimately activate. The sensory pathways from sense organs to the cortex run as a discrete fibres. As for example, if a sensory (fibre for pressure receptor is stimulated then the sensation evoked is one of the pressure.)

4. **Projection.** When any part of the sensory pathway is stimulated, conscious sensation is referred to the location of the receptor and is called the law of projection. As for example, if a cortical area for impulses from the left hand is stimulated, the subject reports pains in his left hand but not in the head.

5. **Intensity discrimination.** The intensity of stimuli is transmitted to the brain by variation of the frequency of action potentials generated by the particular receptor and by variation in the number of receptors achieved. The magnitude of the sensation perceived is proportional to the log of the intensity of the stimulus and this is called **Weber-Fechner law** and expressed mathematically: $S = K \log I/I_o$ where S is the intensity of sensation felt, I is the intensity of stimulus for evoking the sensation, I_o is the threshold stimulus-intensity and K is constant. It has been modified further that the magnitude of a sensation is the power function of the intensity of stimulus. The rhythmic discharges from a particular group of receptors constitute the sensory code for transmission.

6. **Recruitment.** According to the strength of stimuli the number of sense organs are activated but when the strength is increased a large number of receptors are recruited.

7. **Adaptation.** If a sensory organ is stimulated for some time then the frequency of discharge from that organ is gradually declined though the constant stimulation is continued. This phenomenon is known as *adaptation*. There are slowly adapting receptors and rapidly adapting receptors. In slowly adapting receptors like the muscle spindles, with the onset of stimulation the frequency of discharge is increased initially but declines slowly (FIG. 5.71). On the other hand, in rapidly adapting



FIG. 5.71. It shows the nature of discharge in slowly adapting receptors. Such receptors, with the starting of stimulation, adapt very slowly showing gradual decrease of rate of discharge.

receptors like the hair receptors of the skin or of the Pacinian corpuscle, the frequency of discharge is increased initially but declines abruptly and becomes silence although the stimulation is applied constantly (FIG. 5.72).



FIG. 5.72. It shows the nature of discharge in rapidly adapting receptors. Such receptors adapt very rapidly as evidenced from rapid abolition of discharge though the stimulus is continued.

8. **Inhibition.** Sometimes efferent inhibitory axons may impringe on the dendrites of receptors. If such inhibitory axons are stimulated then these axons inhibit the discharges of receptors they innervate. This process is known as *inhibition*. Crayfish stretch receptors are supplied with such inhibitory axons coming from a centrally located cell body (FIG. 5.19E)

These inhibitory axons terminate in close apposition to the stretch sensitive dendrite of the receptor. On excitation of the inhibitory axons, firing of receptors due to constant stretch ceases (FIG.5.73).

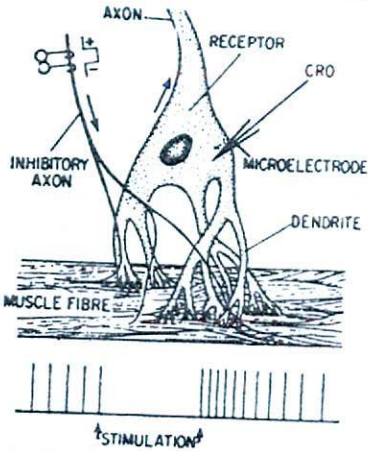


FIG. 5.73. It shows the inhibition in stretch receptors by the inhibitory axon. The inset (*lower part*) shows the inhibition of discharge during stimulation.

Motor end-plates and acetylcholine

Acetylcholine released at the neuromuscular junction to the skeletal muscle causes muscle contraction. The access of acetylcholine to the motor end-plate is blocked by curare and gallamine which lead to paralysis of voluntary movement. Succinylcholine and decamethonium may also combine with receptor sites on the motor end-plate leading to persistent depolarisation of muscle membrane and paralysis of the muscle.

In myasthenia there is an abnormal response of the motor end-plate to acetylcholine and fatigablity (especially of the facial muscles) is produced. This may be due to failure of acetylcholine synthesis and hence really a presynaptic defect. The relationship to the thymic gland in myasthenia may be associated with the formation of antibodies against the neuromuscular junction.

The following observations prove that acetylcholine is produced at the motor end-plates and transmits the impulse to the muscle:

1. **Liberation of acetylcholine in the muscles.** Tongue or hind limb of a cat is perfused with a fluid containing eserine. [The latter neutralises the action of *choline esterase* in muscle, which destroys acetylcholine.] If then the hypoglossal nerve or the motor nerve to the hind limb be stimulated, acetylcholine is found in the outflowing fluid. This shows that it is actually produced in the muscles when the motor nerve is stimulated.

2. **Acetylcholine as the cause of contraction.** Intravenous injection of acetylcholine, in very small doses, causes muscular twitch.

3. **Choline esterase destroys acetylcholine.** Muscles contain an enzyme—*choline esterase*—which hydrolyses and destroys acetylcholine. This enzyme ensures that acetylcholine, normally liberated at the motor end-plates, may only give a single twitch and may not produce any prolonged cumulative effect.

4. **Action of anticholine esterases.** Eserine, prostigmine and such substances neutralise the action of choline esterase and thus enhance and prolong the action of acetylcholine.

5. **Action of curare.** *Curare* is a drug which paralyses the motor end-plates. It does not inhibit the production of acetylcholine but in some unknown way prevents its action (competitive inhibition).

6. **Myasthenia gravis** is the clinical condition when the release of ACh from nerve terminals is interfered with. Myasthenia gravis may

present clinically with ptosis (drooping eyelids), double vision (diplopia), toneless voice or fatigue on chewing and swallowing.

Classification and varieties of nerve endings

According to structure and function, the nerve endings may be of various types (Figs. 5.74 & 5.75). The following is a brief list of both somatic and autonomic nerve endings.

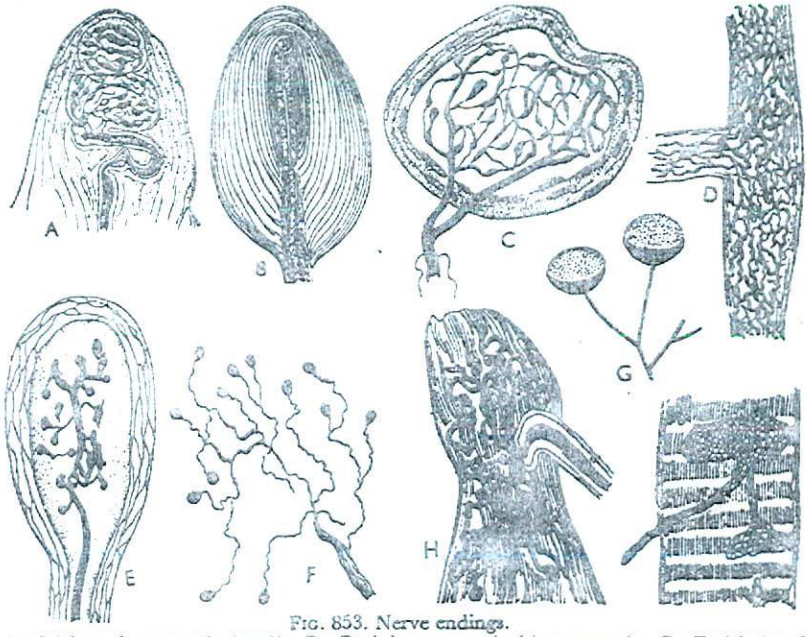
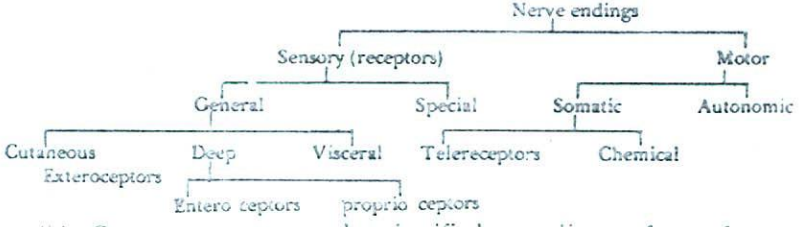


FIG. 853. Nerve endings.
A=Meissner's corpuscle (*touch*); B=Pacinian corpuscle (*deep pressure*); C=End bulb of Krause (*cold*); D=End organ of Ruffini (warmth); E=Organ of Golgi-Mazzoni (*heat*); F=Free nerve terminals (*pain and touch*); G=Merkel's disc (*touch*); H=Golgi bodies or organ of Golgi; I=End-plates.



(b) Receptor organs are also classified according to form of energy hey respond to

)Mechanoreceptors – e.g. touch, pressure 2)Chemoreceptors – taste, smell. i) Thermal receptors – warmth, cold 4)Osmoreceptors. 5) Electromagnetic eceptors – rods & cones 6) Nocieptors – pain nerve endings.

GENERAL SENSES

A. Cutaneous endings – carrying superficial sensation.

(*i*) Having a special connective tissue body. 1. For **touch** (simple contact) *tactile corpuscles* (Meissner's corpuscles), *Merkel's discs.*

2. For **deep pressure** (distortion)—*Pacinian corpuscles.*

3. For **heat**—*end organs of Golgi-Mazzoni* and *of Ruffini.*

4. For **cold**—*end bulb of Krause.*

(*ii*) **Free nerve terminals** (without any special body).

1. For **pain**—probably always free nerve terminals.

2. For **touch**—free terminals around hair roots help touch sensation.

Free nerve endings mediate deep sensation of pain. These are present in between the muscle fibres in tendons and joints.

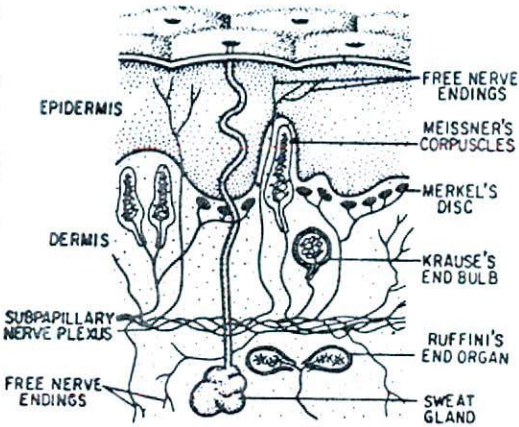


FIG. 5.75. Diagrammatic representation of nerve endings found in dermis and epidermis of human finger-tip showing two papillary ridges.

B. **Deep endings** (Kinaesthetic or proprioceptive).

1. **Proprioceptors of muscles, tendons and joints**—for kinaesthetic impulses, i.e., stretch, tension, etc. All possess special connective tissue bodies: (*a*) *muscle receptors*, (*b*) *Pacinian corpuscles*, (*c*) *uncapsulated nerve endings.*

There are two types of muscle receptors such as (*i*) *muscle spindle* and (*ii*) *Golgi tendon organ.*

Muscle spindle (FIG. 5.76) is a special type of receptor present within the muscle. Each muscle consists of a bundle of *two to ten* slender striated muscle fibres enclosed within a thin connective tissue capsule. The capsule

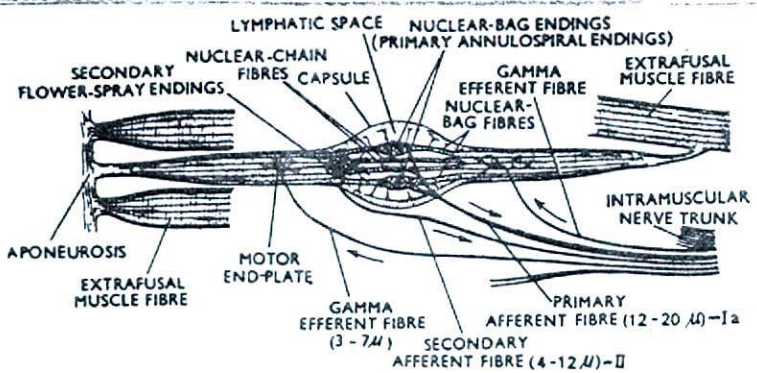


FIG. 5.76. Diagrammatic representation of a muscle spindle.

is tapered at both ends. The modified muscle fibres within the capsule are known as *intrafusal fibres.* The capsule is attached at either tapering end to the endomysium of the *extrafusal muscle fibres* or to the tendon or to the extrafusal muscle fibres. Thus the capsule of the intrafusal muscle

fibres is arranged in parallel with the extrafusal fibres. Boyd (1962) from histological studies has classified the intrafusal fibres into two groups: (*i*) **nuclear-bag fibres** displaying an aggregation of nuclei in the equatorial part, and (*b*) **nuclear-chain fibres** with only a single row of nuclei lying in a chain (FIG. 5.77). The both intrafusal fibres at its terminal ends (polar ends) are striated and contractile, whereas the central end of each fibre is unstriated, probably non-contractile. This portion is known as *nuclear-bag region*. This is separated from the connective tissue capsule by a lymph space filled with tissue fluid and traversed by nerve fibres and connective tissue fibres. At a distance the space on either side of the nuclear-bag region (*primary annulospiral region*) where the nuclei are arranged in central core, is called nuclear-chain region.

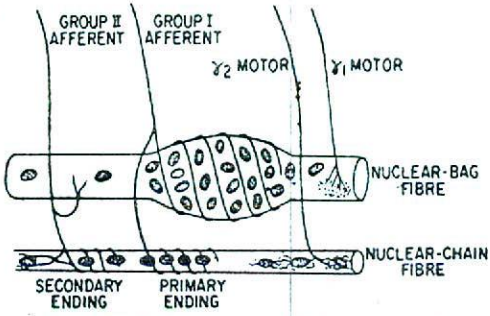


FIG. 5.77. It shows a simplified representation of the central region of the muscle spindle (*after Boyd*).

Viscous nuclear-bag fibres are innervated by γ_1 motor nerve fibres. These γ_1 fibres terminate in discrete polar end-plates. On the other hand, the finer γ_2 motor fibres end in γ-trails on the nuclear-chain fibres and form a diffuse terminal reticulum along much of polar regions of the chain fibres.

From functional studies of isolated innervated mammalian spindles in 1969 Boyd has advocated that γ_1 motor fibres act as dynamic fusimotor fibres, whose primary action is to alter dynamic sensitivity of the primary annulospiral endings during muscle stretch. On the other hand, the γ_2 motor fibres increase the static sensitivity of the primary ending to maintain changes in the length of muscle fibres.

Three types of nerve fibres supply this special type of muscle. Large afferent nerve fibres of 12–20 μ in diameter and having 70–120 m/sec. conduction velocity, known as primary afferent fibres—Ia, end in the nuclear-bag region. Before ending in the intrafusal fibres they loose their myelin sheaths and finally wind round the muscle fibres forming a spiral ending. The second groups of nerve fibres (Group II), known as secondary afferent fibres of 4–12 μ in diameter and having conduction velocity of 30-70 m/sec., enter the spindle to form a small ring which coils or sprays like varicosities on either side of the nuclear-bag region. These types of endings are known as *secondary flower-spray endings*. Third sets of nerve fibres are fusimotor fibres or gamma efferent fibres of 3–7 μ in diameter, enter each spindle and end at the motor end-plates of tapering polar regions (contractile and striated ends) of the intrafusal fibres. The extrafusal fibres are supplied by alpha motor fibres. Afferent fibres from the muscle spindle enter the spinal cord and synapse in the alpha motor neurone (FIG. 5.78) from which the alpha efferent fibres arise, and then a monosynaptic path is established and acts as *stretch or myotatic reflex*.

Golgi tendon organ lies in the tendon and in tendinous band and aponeurosis within the muscle, and is a simple receptor and receives myelinated Group Ib fibres having diameter of 12–20 μ and conduction velocity of 70–120 m/sec.

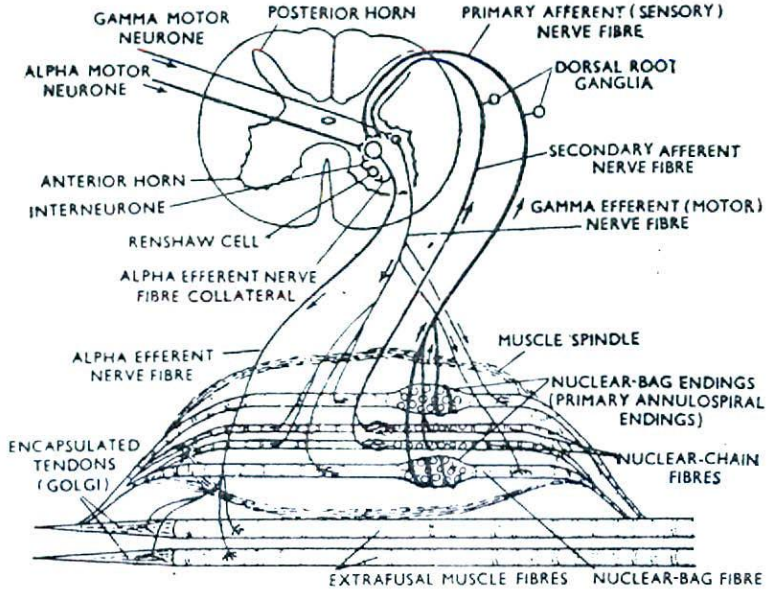


FIG. 5.78. Diagrammatic representation of the afferent and efferent connections of the extrafusal fibres (ordinary muscle) and intrafusal fibres of muscle spindle with the spinal cord motoneurones. Secondary and primary afferent fibres carrying impulses from the muscle spindle end in the alpha motoneurone of the spinal cord through dorsal root ganglion. Gamma efferent fibres from the spinal cord end in the end-plate of the intrafusal fibre of the muscle spindle. Alpha efferent fibres end in the end-plate of the extrafusal fibres. A subsidiary Renshaw interneurone conducting system is also shown to stabilise the activity of the alpha motoneurone.

Both the muscle receptors are stimulated by stretch but the threshold for stimulus is higher for Golgi tendon organs than that of the muscle spindle.

The muscle spindle is stimulated following a little stretch or contraction of the localised poles of the intrafusal fibres due to gamma motor

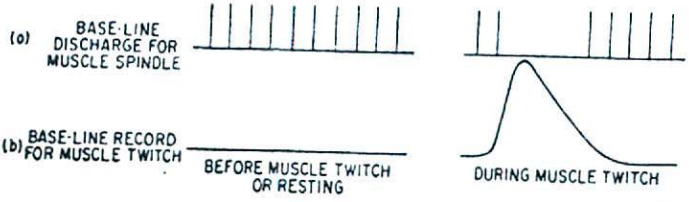


FIG. 5.79. It demonstrates the nature of spindle discharge from spindle afferent fibres during contraction of extrafusal muscle fibres. (*a*) shows *base-line* discharge from muscle spindle afferents during rest and activity of the extrafusal fibres. (*b*) shows records of muscle twitch during rest and activity.

(fusimotor) activity. As the intrafusal fibres are arranged in parallel with the extrafusal fibres, the contraction of the latter reduces the tension in the muscle spindle. Afferent discharges from the muscle spindle afferents (Ia) thus decrease during muscle (extrafusal) contraction (FIG. 5.79). Golgi tendon organs are not stimulated by fusimotor activity and stimulated during excessive stretch as in case of clasp knife reflex. Clasp knife reflex is a disynaptic reflex. Myotatic or stretch reflex is a monosynaptic reflex and mediated by the muscle spindle afferents (Ia). Muscle tendon organs discharge profoundly during muscular contraction (contraction of the extrafusal fibres) causing excessive stretch of the muscle tendon (FIG. 5.80) but remains practically silent during rest of the muscle.

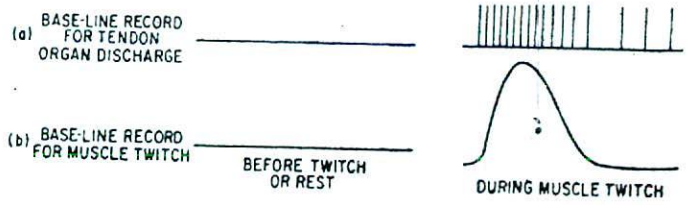


FIG. 5.80. It demonstrates the nature of activity of tendon organ afferents during rest and activity. (*a*) shows the records of pattern of discharge during rest and activity. (*b*) shows records of muscle twitch during rest and activity.

SUMMARY. The neuronal mechanism of the stretch reflex at the spinal level may have at least three types of afferent nerve fibres: (*a*) primary spindle afferent (Group Ia), (*b*) secondary spindle afferent (Group II) transmitting its impulses to the spinal cord along smaller diameter and therefore more slowly conducting fibres, (*c*) Golgi afferent (Group Ib) producing autogenetic inhibition at high tension. The central connections between incoming afferents and parent motoneurone pool may be direct (monosynaptic excitatory) or *via* interneurones. The descending impulses may modify the excitatory activity of these interneurones. The motor output is in two parts: (*a*) the γ-outflow(s) to the intrafusal muscle fibres by means of which the sensitivity of spindle afferents to stretch may be modified, and (*b*) the α-motoneurone output (the final common path) by which the contraction of extrafusal muscle fibres is ultimately achieved. In addition to the afferents from muscle, other reflex pathways may converge on the large (α-) motoneurones and modify stretch reflex. Cutaneous sensations and especially pain are suitable examples.

Pacinian corpuscles are oval bodies and composed of concentric laminae. The afferent fibre penetrates to the centre of the corpuscle and pressure is the adequate stimulus. These receptor organs are present in baroreceptors, tendons, joints and periosteum, beneath the tendinous insertion and in subcutaneous tissues. These are also present in the abdominal mesentery. Microdissection demonstrates that a series of layers are separated by small amounts of fluid. In the centre there are blood vessels and a single nerve ending. The final portion of the nerve is unmyelinated, but there is one complete length of myelin and one node of Ranvier within the corpuscle (FIG. 5.68).

2. **Labyrinthine impulses**—*saccule*, *utricle*, etc. [*Vide* 'Vestibular Apparatus': *Otolith Organs*.]

C. **Visceral** (Autonomic). Either free terminals or special cells.

1. For **pain**—non-medullated *free terminals*.

2. For **stretch** and **tension** (hollow organs, capsules, serous membranes, etc.). *Free terminals*—as in carotid sinus and aortic arch. [Pacinian corpuscles are also found in the viscera and peritoneum—probably subserving stretch and tension.]

3. **Chemoreceptors***—sensitive to chemical changes of blood. These are special types of cells as found in *carotid and aortic bodies*.

SPECIAL SENSES

A. **Telereceptors** (distance receptors).

1. For **vision**—*rods* and *cones* (retina).

2. For **hearing**—*organ of Corti* (internal ear).

B. **Chemical receptors.**

1. For **taste**—*taste buds*.

2. For **smell**—*olfactory cells*.

II. **Motor endings**

(*i*) **With special connective tissue body** (somatic)—*motor end-plates*—in the voluntary muscles.

(*ii*) **Free nerve terminals** (autonomic)—supplying plain and cardiac muscles, blood vessels, glands, etc.

Some important **nerve endings** (FIGS. 5.64, 5.65, 5.68, 5.74, 5.76, 5.77 & 5.78) are described below:

Variety	Histology	Distribution	Function
SENSORY			
A. Cutaneous			
1. **Tactile corpuscles** (Meissner's corpuscles)	Ellipsoidal lamellated connective tissue body, soft central core where axis cylinder ends in a complex manner.	Papillae of the skin just under epidermis, specially hands and feet. Only one per 35 sq. mm.	Subserves *touch* (their number being few, there must be other touch endings, viz., free terminals around hair follicles, etc.).
2. **Pacinian corpuscles**	Large oval body, lamellated like *onion*, naked axis cylinder ends in the core by arborisation.	In the dermis, specially of hands and feet. Also in deeper structures like joints, tendons, etc. Also in the viscera, viz., peritoneum.	Carry *pressure*, *stretch* and *kinaesthetic* impulses. Gross deformity of shape is the adequate stimulus.
3. **End bulb of Krause**	Spheroidal connective tissue body, axis cylinder ends in a basket-like network. In animals, oblong or cylindrical. In the duck's bill axis cylinder ends in one or two expansions between 2–3 large core cells.	Conjunctiva, papillae of skin, lips, tongue, genital organs (*genital corpuscles*), in the structures near joints (*articular corpuscles*), epineurium of nerve trunks, etc.	Supposed to carry *cold* sensations.

* **Osmoreceptors.** From recent observations Verney and others postulate the presence of special *osmoreceptors*, sensitive to alterations of osmotic pressure of plasma, which by influencing the hypothalamo-pituitary pathways, regulate the secretion of antidiuretic hormone. [*Vide* the 'Antidiuretic Hormone (ADH)']

Nerve endings (*continued*)

Variety	Histology	Distribution	Function
4. **End organ of Ruffini**	Long cylindrical body, axis cylinder ends in flat expansions.	Skin and subcutaneous tissue of the fingers.	Carry sensation of *heat*.
5. **Organ of Golgi-Mazzoni**	Spheroidal or oval body, axis cylinder ends in flat expansions.	Skin and subcutaneous tissue of the fingers. Also in tendons and fascial sheaths of muscles.	Carry sensation of *heat*.
6. **Free nerve terminals**	The nerves at first form a *deep primary plexus*, then a *superficial secondary plexus*, from which terminal filaments pass to the surface, ramify among and inside the cells. End points have knob-like expansions.	Widely distributed throughout the body. Dermis, cornea, etc. Also found between the muscle fibres, in tendons, fascia joints, serous membrane, etc.	1. Carry *pain* sensation for which there is no organised nerve endings. 2. Carry *touch*. Free terminals in skin and around hair roots are believed to carry touch impulses.
7. **Special receptors**			
(*a*) *Stretch receptors* or *mechanoreceptors*		Carotid or aortic sinus. Lung parenchyma.	Arterial blood pressure regulation. Inflation of lung regulation.
(*b*) *Chemoreceptors*	Chromaphin cells.	Carotid or aortic bodies and great veins.	Partial pressure of O_2 or CO_2 in blood regulation.
(*c*) *Osmoreceptors*	Unknown	Medulla oblongata, Anterior part of hypothalamus.	Osmotic pressure of plasma regulation.
(*d*) *Thermoreceptors*	Unknown	Hypothalamus.	Temperature regulation of blood.
(*e*) *Glucostatic receptors*	Unknown	Hypothalamus.	Inform the arteriovenous glucose difference.
B. Musculotendinous receptors			
1. **Muscle spindle**	Long fusiform body, inside which are a few embryonic muscle fibres (*intrafusal fibres*). The naked axon divides into branches which wind spirally round the intrafusal fibres.	Remain between muscle fibres, with their long axis parallel to the length of the muscles.	Carry *kinaesthetic* impulses, i.e., stretch, tension, pressure, etc.
2. **Golgi tendon organ**	Flat bodies, between bundles of tendon fibres. Naked axon terminates in varicose arborisations.	Found in the tendons near the junction with the muscle.	Carry *kinaesthetic* impulses, i.e., stretch, tension, pressure, etc.

Nerve endings (*continued*)

Variety	Histology	Distribution	Function
MOTOR			
1. **End-plates** (*Vide* pages 5-54, 5-55).	Naked axon is expanded into an end foot (sole foot) which ends into a specialised structure of the muscle membrane (motor end-plate). Sole foot contains mitochondria and vesicles filled with acetylcholine. Muscle membrane (sarcolemma) has got multiple folds which are collectively called synaptic gutter. The sole foot is bathed within the synaptic gutter. The sole foot is separated from the sarcolemma by the synaptic cleft (**palisades**) filled with extracellular fluid. Choline esterase is present in the rim of the synaptic gutter.	In all the voluntary muscles.	Transmits *motor impulses*. *Acetylcholine* is secreted at these endings, which initiates, chemical changes underlying muscular contraction.
2. **Free nerve terminals** (Autonomic only)	The nerves form a *plexus*, from which terminal filaments pass to the surface, ramify among and inside the cells. End points have knob-like expansions.	Involuntary and cardiac muscles, glands, etc.	Transmits *motor impulses*. *Acetylcholine* is secreted at the preganglionic and postganglionic parasympathetic nerve endings and norepinephrine is secreted at the postganglionic sympathetic nerve endings. Preganglionic sympathetic nerve endings also secrete acetylcholine.

REFLEX ACTION

Definition. *Reflex action is an involuntary (automatic) effector response due to a sensory stimulus.* It is the basic physiological unit of integration in the neural activity.

Varieties of reflexes. There are mainly two types of reflexes: (1) **Unconditioned reflexes** or **Inborn reflexes** (*Vide* page 5-81). These are inherent, fixed and cannot be altered normally (2) **Conditioned reflexes.** All are acquired. Can be established and abolished (*vide* under *Conditioned Reflexes*).

Reflex arc

Complete pathway (FIG. 5.81) for a reflex action. Three parts:

1. **Afferent limb**—consists of (*a*) receptor, and (*b*) afferent or sensory nerve fibre.
2. **Centre**—consists of nerve cells where the sensory stimulus is converted into a motor impulse.

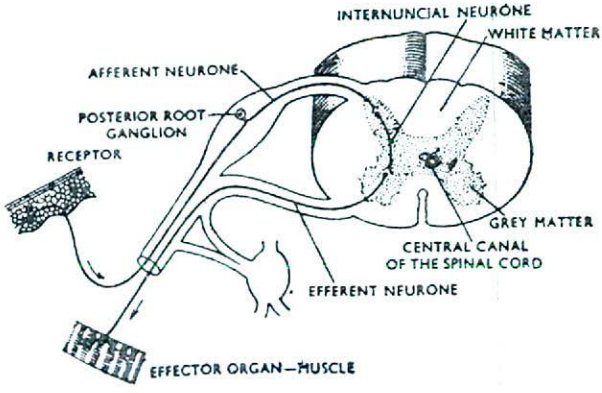


FIG. 5.81. Reflex arc.

3. **Efferent limb**—consists of (*a*) efferent or motor nerve fibre and its endings, (*b*) the effector organ—muscle.
4. **Synapse**—communicating link of two neurones.

Varieties of reflex arcs

1. **Simple or two-neurone reflex arc or monosynaptic reflex arc.** Has two neurones only, e.g., *stretch reflex* (FIG. 5.94).
2. **Three-neurone reflex arc or disynaptic reflex arc.** Extension and crossed extension reflexes are the examples of this arc. There is a connecting neurone in between the afferent fibre and the motoneurone.
3. **Polysynaptic or multisynaptic reflex arc.** Several neurones. One or more internuncial (intercalated) neurones are also involved. **Withdrawal reflex** is a typical polysynaptic reflex and occurs in response to a noxious and usually painful stimulation of the muscles, skin and subcutaneous tissues (FIG. 5.95).
4. **Complex reflex arc.** The axon of a sensory neurone, while passing upwards, gives off collaterals at different levels, each of which may form separate reflex arcs. Thus the same fibre will carry conscious sensations to cortex and also form multiple reflex arcs.
5. **Asynaptic reflex arc.** This reflex arc is not concerned with the synapse or nerve cell and also known as **axon reflex arc.** This is not a true reflex arc, and afferent and efferent limbs of this reflex arc are constituted by the branching of a single nerve fibre. Because the reflex is obtainable even after section of the posterior root peripheral to their ganglia, so long as the cut nerves are not degenerated.

GENERAL CHARACTERISTICS OF REFLEX ACTION

Irradiation. If the sensory stimulus be too strong, the impulse would spread on to many neighbouring neurones in the centre and produce a wider response. For instance, a weak pin prick on the finger will produce a reflex movement of that finger only. But if the prick be too hard, the whole hand will jerk up. If this process continues there will be recruitment of more and more motoneurones. Irradiation is due to transmission of the impulse through a large number of collaterals of the afferent fibres and their interneurones. A strong stimulus will cause reflex contraction of the extensor muscles of the opposite limb.

Delay. There is a short interval between the application of stimulus and the onset of reflex response. This period is called *total reflex delay*. If from this, the time taken by the nerve impulse to traverse the motor and sensory limbs of the reflex arc, be subtracted, the remainder will be the *central delay* (*reduced reflex time*). This time is lost in crossing the number of synapses in the central nervous system. [*Vide* FIG.5.57 in page5-49).and also Synapse.]

Summation. If the stimulus be *subminimal* and applied to an afferent nerve there will be liberation of a chemical transmitter which will cause excitatory postsynaptic potential (EPSP), but this EPSP will not be sufficient to produce discharge of impulses from the motoneurones. But if a number of subminimal stimuli be applied, their effects will be summated together and the EPSP will be sufficient to induce the motoneurones to discharge impulses and produce the reflex response. This is called *summation*. Two types of summation are found: (*a*) **Spatial summation**—Here the subminimal stimuli are applied simultaneously, not on the same spot but at different points on the body (the points should be so selected that from each one the same reflex may be elicited). (*b*) **Temporal summation**—Here a series of subminimal stimuli are applied on the *same spot*, one after the other. The first shock causes a change in excitability somewhere on the pathway of flexion reflex which persists for several msec. to summate with the effect of the second shock. Sherrington called this persisting change *central excitatory state*. It seems that alterations of the central excitatory state during the flexor reflex took place in the motoneurones of the flexor muscle, in the motoneurone pool as it was termed. Electrical recording with fine electrodes inside the spinal cord has now shown that afferent nerve fibres which elicit the flexion reflex, end on the interneurones in the posterior horn of gray matter and do not themselves run through to the motoneurones in the anterior horn.

When the afferent nerves are stimulated simultaneously there is liberation of chemical transmitter substance which causes excitatory postsynaptic potential (EPSP). When excitatory postsynaptic potential is adequate the reflex response occurs. **Scratch reflex**—On repetitive stimulation of the skin behind the ears, neck, shoulder and in a dog after spinal section in the cervical region produces scratching movement of the corresponding hind limb due to alternate contraction of flexor and extensor muscles. The scratch reflex cannot be elicited by electrical excitations of cutaneous nerve trunks or of posterior roots; apparently such volleys are not recognised as objects to be scratched at; but small shocks applied through a fine pin (electric flea) pushed just into the epidermis are successful. Scratch reflex is an example of *temporal summation*.

Occlusion (FIG.5.82). When a reflex contraction is produced by simultaneous stimulation of two afferent nerves, the amount of tension (T) in the muscle is less than the sumtotal of the tensions (t_1+t_2) set up in the same muscle when the two afferent nerves are separately stimulated (i.e., $T<(t_1+t_2)$. This is explained on the assumption that some nerve cells remain common to both the reflex paths (FIG.5.83).

Subliminal fringe. This is exactly the reverse of occlusion. Here the total tension due to separate stimulations (t_1+t_2) is less than the amount of contraction (T) obtained with simultaneous stimulation of the two spots ($T>(t_1+t_2)$). It is explained



FIG. 5.82. Phenomenon of occlusion.
a & b are separate afferent paths each including several neurones. *c* is the common motor path. Note that one neurone is common to both the reflex paths.

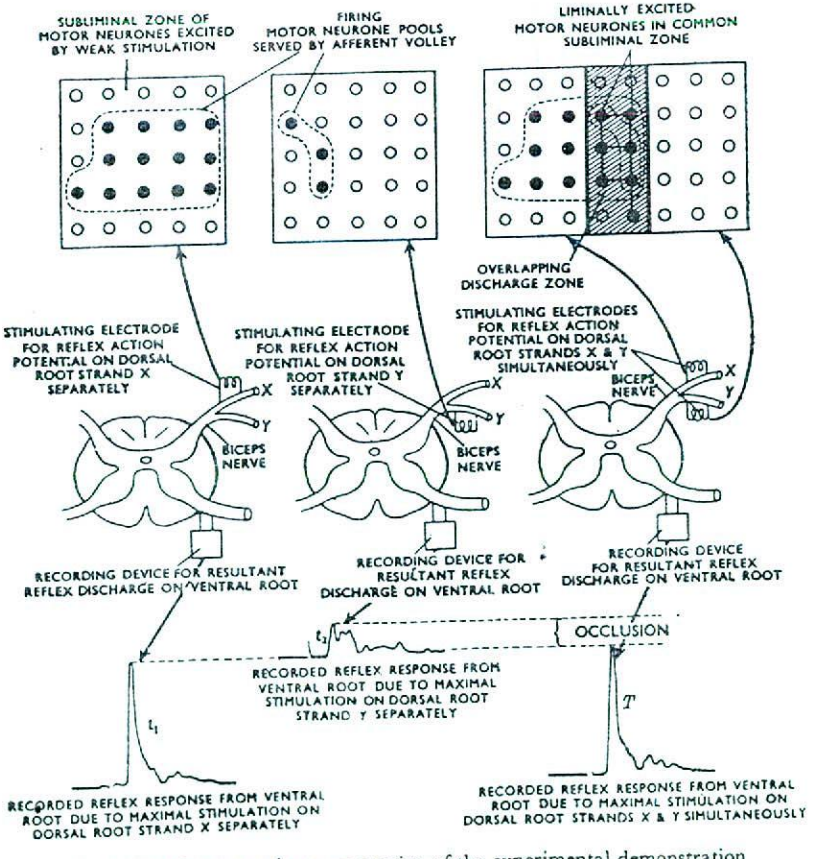


FIG. 5.83. Diagrammatic representation of the experimental demonstration and of mechanism of occlusion.

on the following lines. During separate stimulation, the impulse becomes adequate for some synapses but inadequate (subliminal) for others (high-resistance synapses). But during simultaneous stimulation of two spots, such subminimal stimuli coming from two sources, will be summated together and be able to pass through the high-resistance synapses. So that the effect with simultaneous stimulation will be stronger than the sumtotal of effects produced by separate stimulation (FIG. 5.84).



FIG. 5.84. Phenomenon of subliminal fringe.
When stimulated alone, only the black cell is excited. When stimulated together, the two high-resistance synapses (shaded) which remain common to both the dotted fields, are also excited and the effect becomes greater.

Facilitation. If a reflex be elicited repeatedly at proper intervals, the response becomes progressively higher for the first few occasions. Each subsequent stimulus seems to exert a better effect than the previous one and makes the

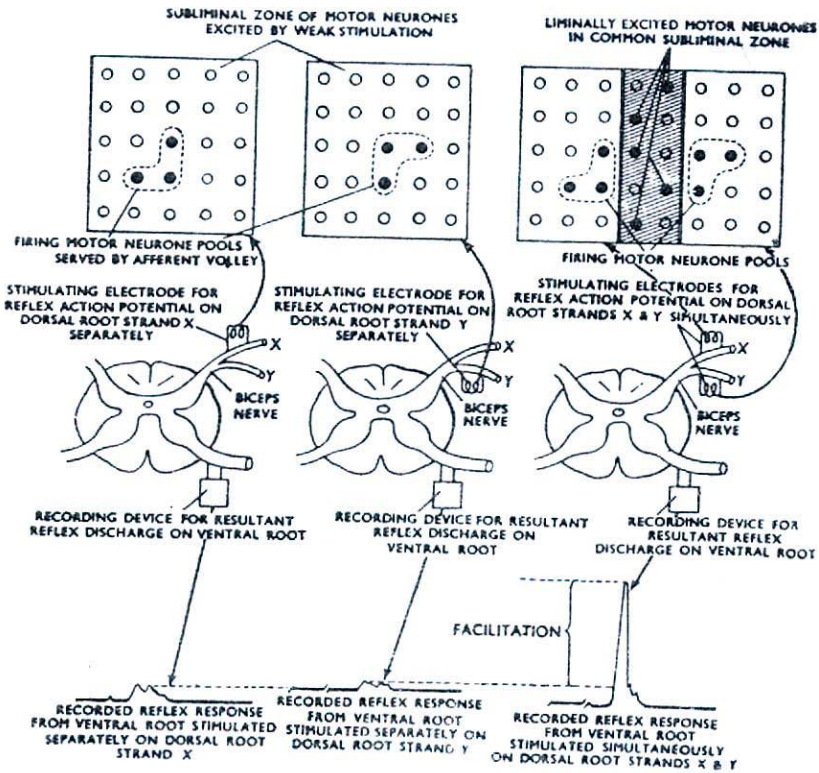


FIG. 5.85. Diagrammatic representation of the experimental demonstration and of mechanism of facilitation.

passage of the next impulse easier. In other words, the passage of a reflex impulse facilitates the transmission of the next impulse (*beneficial effect*—by reducing synaptic resistance). The change of state by which the second subliminal impulse is rendered liminal is spoken of as *facilitation* (FIG.5.85).

Inhibition. In this phenomenon a stimulus diminishes or inhibits the effects of another stimulus. Impulses through the sensory fibres from protagonist muscles lead to a reflex response of those muscles but at the same time inhibit the action of the antagonist muscles. Sherrington demonstrated that when the flexor muscles of a joint are stimulated the extensor muscles are inhibited. Such reciprocal effects are due to the inhibitory activity exerted by the interneurones.

Recruitment. When muscle fibres are stimulated directly through their motor nerve, the tension *very quickly* rises to the maximum. But if they are stimulated reflexly through a sensory nerve, the tension in the muscle develops *gradually* to the peak. After repeated stimulation of the afferent nerves more internuncial neurones are activated and lead to excitation of more number of the motoneurones. If the stimulation is continued, effective summation occurs. All these effects may be said as due to the recruitment of more and more motoneurones. But there is always a limit of recruitment.

After-discharge. After reflex contraction (by tetanising current) if the stimulation is discontinued, the muscle does not completely relax at once. It relaxes gradually. Certain amount of contraction lingers in the muscle for some time. This is due to the fact that the centres go on discharging motor impulses for a brief period, even after the sensory stimuli are stopped. It is due to stimulation of the motoneurones through the internuncial paths. The impulses which travel in the internuncial paths (long or delay paths) take longer time to reach the motoneurones. So even after cessation of afferent stimulation these impulses travel for certain periods and stimulate the motoneurones.

Fatigue. If a particular reflex be repeatedly elicited at frequent intervals, the response becomes progressively feebler and finally disappears altogether. This phenomenon is called *fatigue*. The seat of fatigue is in the central nervous system, probably at the synapses. Because a muscle, under reflex fatigue, will contract when the motor nerve or the muscle itself is directly stimulated. *Fatigue comes first at the synapses, then in the motor endings and lastly in the muscle.*

Fractionation. When a stimulus is applied directly on the motor nerve of a muscle, the amount of contraction becomes much higher than when the same muscle is made to contract reflexly (i.e., by stimulating the appropriate sensory nerve). This indicates that one fraction of the sensory impulse is lost in the central nervous system apparently to overcome the synaptic resistance (strength of the impulse is reduced while crossing a synapse). A portion of the motor neurone pool supplying the muscle is only stimulated. There is also graded response in flexor reflex and crossed extensor reflex with simultaneous increase in the strength of stimulus.

Reciprocal innervation. In a reflex action when one group of muscles contracts, the antagonistic group relaxes to the same degree. In a decerebrate animal the flexors of the knee and their antagonists the extensors when detached from their insertions and the sole of the foot is stimulated contraction of the flexors and relaxation of the extensors

occur. Both the processes occur simultaneously. The changes are recorded by connecting the muscles with the levers. The afferent impulses pass by dorsal root into the spinal cord, stimulate the motoneurones supplying the flexors and inhibit the motoneurones supplying the extensors (FIG. 5.86). [Sherrington.]

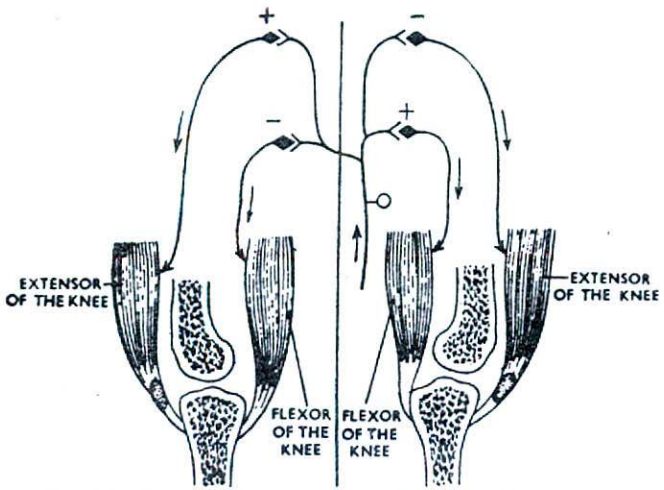


FIG. 5 86. Reciprocal innervation [modified after Sherrington].

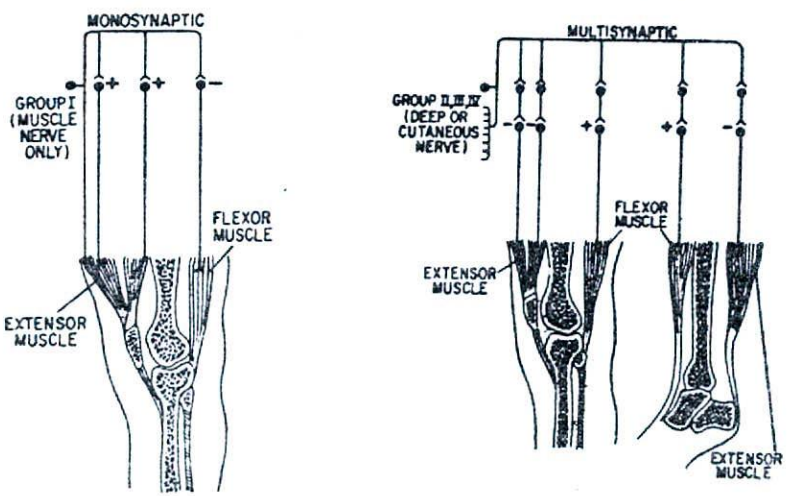


FIG. 5 87 (a). *(after Ruch and Patton)* FIG. 5 87 (b).

'+' stimulation; '−' inhibition.

Reciprocal relations of monosynaptic and polysynaptic reflex arcs have been shown in FIG. 5.87 (a) & (b). If Group II, III and IV afferent fibres are stimulated, then they influence diffusely, motoneurones

upplying muscles acting at several joints. If the Group I afferent is stimulated hen it influences the motoneurone supplying muscles acting at a single joint.

Rebound phenomenon. Just as a muscle can be reflexly excited, so also it an be reflexly inhibited (tone reduced and muscle elongated due to elaxation—*Reflex inhibition*). After such reflex inhibition with a tetanising urrent, if the stimuli be stopped, the muscle instead of going back to its ormer length, becomes shorter. In other words, the muscle tone increases bove the normal resting value. This is called *rebound phenomenon.*

Final common path. All neural influences affecting muscular contraction pass through final common paths which receive numerous converging input ignals at a particular spinal segment from various spinal and supraspinal nhibitory and excitatory pathways.

Central excitatory and inhibitory states. The spinal cord at a particular evel shows prolonged changes in excitability resulting from the activities of reverberating circuits of the segmental and suprasegmental pathways and he particular prolonged state of activity is called excitatory or inhibitory tate.

UNCONDITIONED REFLEXES

As mentioned before, unconditioned reflexes are inborn. The nerve paths are fixed from the very birth. Any material alteration is considered as disease. Hence, examination of reflexes is a great help in the diagnosis of various diseases.

Classification of reflexes

[A] **Physiological :**

1.) Segmental : The reflex arc passes through only one segment of the spinal cord e.g. tendonjerk

2.) Intersegmental : The arc involves tracts of spinal cord in different segments, e.g. crossed extensor

3.) Suprasegmental : The arc involves nuclei above the cord and the segments of cord itself. e.g. attitudinal postural reflexes.

[B] **Clinical :**

1.) Superficial – elicited from skin or mucous membrane. e.g.Corneal, plastar etc.

2.) Deep – elicited from tendons, e.g. tendon jerk.

3.) Visceral – elicited from organs, e.g. digestive, micturition reflex etc.

4.) Pathological – are present only in abnormal condition e.g. Babinski's sign.

Superficial reflexes

Stimulation of certain areas of skin or mucous membrane causes contraction of corresponding muscles. Due to their surface origin they are

called *superficial reflex*. The examples are **plantar reflex, abodorninal reflexes cremasteric reflex, conjunctival reflex, corneal reflex,** etc.

Brief details about some important superficial reflexes are given below :

Superficial Reflexes	Method of Eliciting	Response	Centre
Plantar	Scratching the skin of the sole.	Normally planter flexion of the great toe (Fig. 5.88 A). But in case of infants (before walking) and also in pyramidal lesions (corticospinal at any level above the 1st sacral segments, the normal response is changed into dorsiflexion of the great toe and often associated with fanning of the outer toes (Fig. 5.88 B).	Lumbar 5 to Sacral 2. Most probably the Sacral 1.
Bulbocavernous	Stimulation of glans penis.	Contraction of the bulbocavernosus muscle.	Sacral 3 & 4.
Anal	Scratching of the neigh bouring skin of the anal sphincter.	Contraction of external and sphincter.	Sacral 4 & 5 and Coccygeal segments.
Gluteal	Scratching the skin of the buttock.	Contraction of the gluteal muscles.	Lumber 4 & 5 and Upper sacral segments.
Upper abdominal (Epigastric)	Scratching below costal margin.	Retraction of hypochondrium of the same side.	Thoracic 6 & 7.
Lower abdominal	Stroking above the inguinal ligament.	Contraction of the lower abdominal wall on the same side.	Thoracic 10 & 12.
Cremasteric	Stroking skin of inner thigh.	Drawing up of testicle.	Thoracic 12 to Lumbar 2.
Conjunctival and Corneal	Touching conjunctiva or cornea.	Winking.	Nuclei of Vth & th cranial nerves.

* The reflex arcs for superficial reflex are not definitely known. They seem to be long and complex, including a number of intercalated neurones. The impulse appears to be carried up by fibres in the posterior column tracts and spinothalamic tracts and ends somewhere in the midbrain, thalmus or even the forebrain. From these region, it is then carried down by the pyramidal, or more probably the extrapyramidal tracts (being more primitive) and is passed on to the corresponding anterior horn cells. The nerve path for deep reflexes, on the other hand, is simple and short, ending quickly in the cord itself. This explains why in the case of upper motor lesions, the superficial reflexes are lost (reflexes are damaged), but the deep reflexes are exaggerated (release phenomenon).

Babinski's sign (FIG.5.88B). In pyramidal lesions, the plantar response becomes extensor, i.e., infantile type. The explanation is as follows: Dorsiflexion of ankle and toes (the so-called *extension*) is physiologically a *flexion* movement. *Spinal cord favours flexor tone.* Hence, scratching the 'sole' produces an extensor response in infants. But when the baby learns walking the response becomes flexor (plantar flexion). Because the pyramidal tracts grow (15–18 months) and inhibit the extensor muscles and thus flexors become relatively strong. Hence, *after infancy, the response is normally 'flexor'*. Obviously this is a great help in walking. The touch of the ground acts as the 'scratch' which reflexly causes plantar flexion of the toes—which thus presses upon the ground at each step and helps in thrusting the body forwards. In pyramidal lesions this inhibition upon the extensors is removed, hence response reverts to the primitive type and becomes extensor. Thus it should be regarded as a **release phenomenon.**

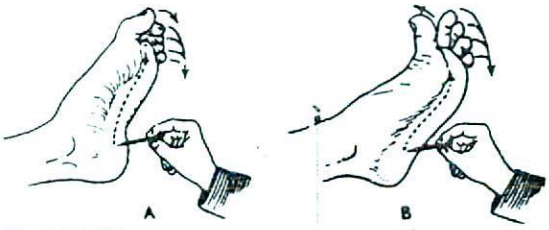


FIG. 5 88. Diagrammatic representation of plantar reflexes. A = Normal plantar reflex. B = Babinski's plantar reflex.

Deep reflexes or Tendon reflexes

Brief details about some important DEEP REFLEXES are given below:

Deep Reflexes	Method of Eliciting	Response	Centre
Knee jerk or Patellar tendon reflex	Tapping patellar tendon.	Jerking forward of leg.	Lumbar 2 to 4.
Ankle jerk or Achilles tendon reflex	Tapping tendo-achillis.	Plantar flexion of foot.	Lumbar 5 to Sacral 2.
Jaw jerk	Tapping the chin with the mouth partly open.	Jerk the jaw.	Pons.
Biceps jerk	Tapping biceps tendon.	Flexion of forearm.	Cervical 5 & 6.
Triceps jerk	Tapping triceps tendon.	Extension of forearm.	Cervical 6 to 8.
Supinator jerk	A blow upon the styloid process of the radius.	Contraction of supinator and flexion of the elbow.	Cervical 5 & 6.

Tendon reflexes are deep proprioceptive (kinaesthetic) reflexes and should be regarded as *fractionated stretch reflexes*. A sharp tap on the slightly stretched tendon, will elicit an equally sharp contraction of the corresponding muscles. These reflexes show characteristic variations in many diseases

and are of great diagnostic value. Knee jerk (FIG. 5.89B), ankle jerk (FIG.5.92), biceps jerk (FIG.5.89A), triceps jerk (FIG.5.89C), etc., are the examples. Knee jerk is briefly described below.

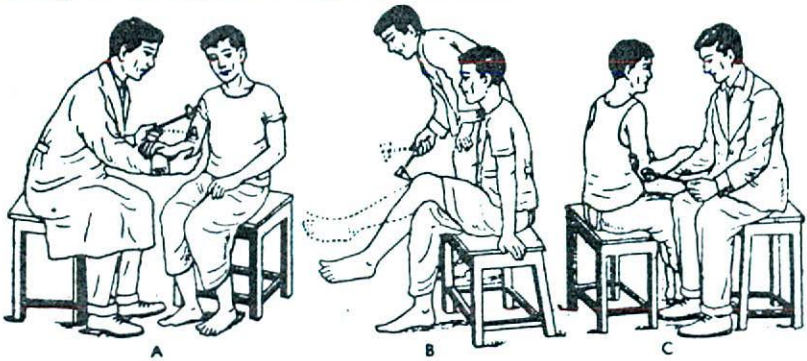


FIG. 5 89. Diagrammatic representation of reflexes. A=Biceps tendon reflex (*flexion of forearm on percussion of biceps tendon*). B=Patellar tendon reflex or knee jerk (*extension of leg on percussion of patellar ligament*). C=Triceps tendon reflex (*extension of forearm on percussion triceps tendon*).

Patellar tendon reflex or Knee jerk. Knee being semiflexed, a sharp tap on the patellar tendon causes contraction of the quadriceps and the leg jerks up (FIGS. 5.89B &5.90).

Reflex path. The sharp tapering on the patellar tendon causes stretch on the muscle spindle of the extensor muscle (*vide* page 5-70). and afferent impulses pass through the primary afferent fibres to the spinal motoneurone *via* dorsal root ganglion. This afferent fibre synapses with the alpha motoneurone of the spinal cord (FIG. 5.91). The impulse thus reaching the spinal cord stimulates the alpha motoneurone and the contraction of extensor extrafusal muscle fibres occurs. With this a short jerky forward movement of the leg occurs. It is a *monosynaptic reflex*. For this jerky movement the flexor muscles relax, simultaneously with the contraction of the extensor (FIG.5.90), due to inhibitory motor influences exerted on the antagonistic muscle group during reflex. With the short

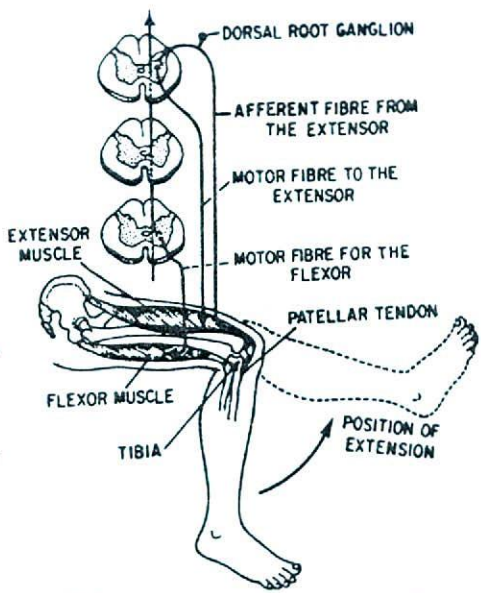


FIG. 5 90. Diagrammatic representation of tendon reflex (knee jerk or patellar tendon reflex) along with patellar tendon of extensor muscle attached to the tibia below the knee.

twitch contraction of the extrafusal fibres of the extensor muscle, the stretch tension in the muscle spindle is lessened followed by sharp cessation of

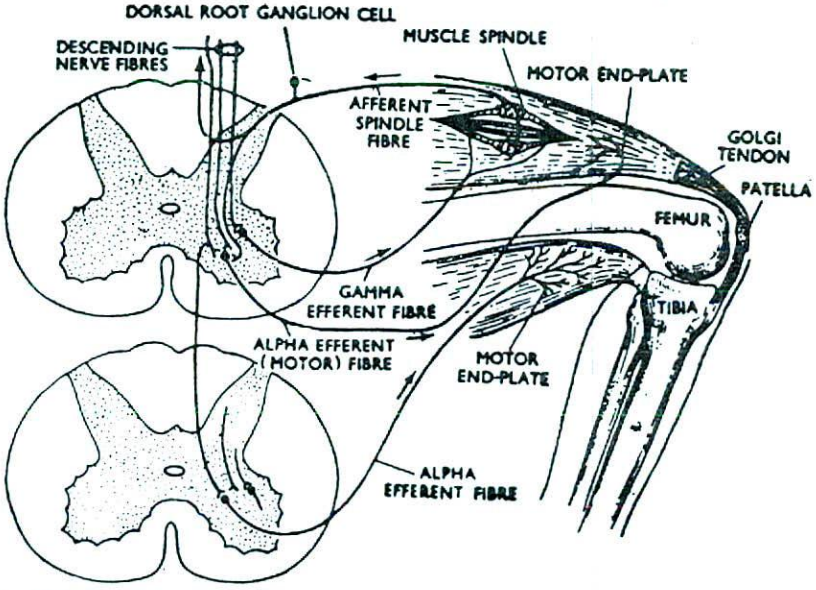


FIG. 5 91. Diagram showing mediation of myotatic reflex pathway of afferent and efferent fibres and principal receptors of muscle spindles. It also shows the *gamma motor loop system* comprising the afferent and efferent connections in between the muscle spindle and the spinal cord motoneurone.

the above reflex and thus relaxation of extensor muscle simultaneously with contraction of the flexor occurs. Renshaw cells of the spinal cord are stimulated during the alpha motoneurone activity and inhibit in turn the alpha motoneurone discharge (FIG.5.58).

Reinforcement. Knee jerk may be reinforced by a strong simultaneous voluntary act, viz., clenching the jaw, squeezing the hands, etc. Reinforcement is due to overflow (irradiation). When the voluntary act precedes the reflex by a long interval (0·5 second), the jerk is inhibited. This is called **negative reinforcement.**

Knee jerk is abolished in lower motoneurone lesions, exaggerated in upper motoneurone lesions, and becomes pendular in certain cerebellar diseases.

Knee clonus or Patellar clonus. This is found when knee jerk is highly exaggerated and is a dependable sign of the upper motoneurone lesion. When the patella is sharply pressed down, the quadriceps show a series of clonic contractions as long as the stretch is maintained. *Clonus is nothing but 'repeated jerk'.* As soon as the muscle relaxes the maintained patellar pressure stretches the muscle again, so that the muscle again contracts. This alternate contraction and relaxation will go on rhythmically, as long as the pressure is continued.

Ankle jerk. The jerk represented in FIG.5.92 is an ankle jerk. According to P. A. Merton, the reflex is elicited by striking the tendon of ankle extensors (soleus and gastrocnemius muscles) with a specific hammer. It

consists of a twitch contraction of these muscles. To record the contraction, the foot rests on a board. Contraction of ankle extensors causes an increase in the downward pressure, exerted by the front of the foot on the board, which is recorded on a CRO. The action potential of ankle extensors is led off by surface electrodes on the calf muscle.

Oscilloscope time base is triggered by contact of the hammer with the skin over the tendon. The blow itself causes a short rise in tension which appears as a small hump before the beginning of muscle twitch. If the latency of the reflex be measured from the contact of the hammer with the skin to the start of the action potential, it would be about 45 msec. On the other hand, nerve conduction time is about 35 msec., together with a brief central delay, from the muscle to the spinal cord and back again,

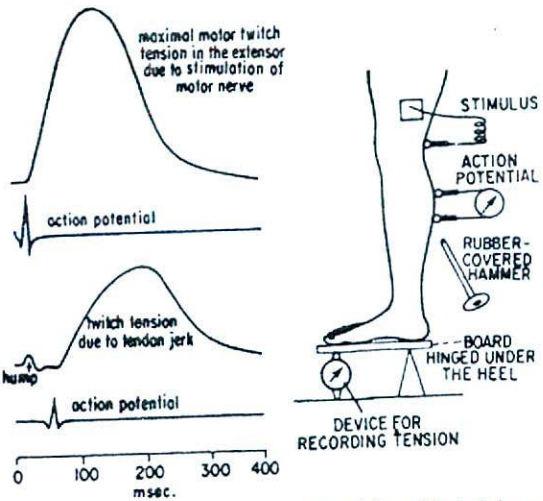


FIG. 5.92. Diagrammatic representation of the ankle jerk in man (*after Lippold & Winton*).

An optimal motor twitch in the extensor muscle, elicited by an electrical stimulus to the motor nerves, is shown in FIG. 5.92. The time base is triggered by stimulus. The action potential and twitch tension are larger and the latency is much shorter. But the duration of the action potential and the twitch are much the same as in the reflex jerk, showing the reflex discharge with a highly synchronous volley of nerve impulses.

Ankle clonus. In pyramidal lesions, sudden dorsiflexion of the foot, will cause rhythmic contractions of the calf muscles—producing ankle clonus. It will continue as long as the flexion is maintained. This is seen in upper motoneurone lesions only. The explanation and significance are same as patellar clonus.

[The jerk is reflex. Because it disappears if either the sensory or motor fibres to muscles are interfered with. The latency is about 20 msec. for the human knee jerk, little more than is needed for conduction time to the spinal cord and back. Experiments on animals have shown that the central delay is less than one msec., time for only one synaptic junction to be passed. Afferent impulses that excite the reflex arise in the fleshy part of

the muscle, not in the tendon; striking the tendon is effective only because it causes a sudden rapid slight elongation of the muscle. The initial rapidity of stretch is the essential feature; slower stretch of larger amplitude cannot elicit a jerk. The initial rate of stretch needed to elicit a tendon jerk is much greater than is normally imposed on the muscles by movements of joints, or than is used by the physiologist to elicit the stretch reflex.]

Stretch reflexes (Myotatic reflexes)

When the tendon of a *denervated* muscle is pulled upon, the muscle passively elongates. But if the same pull is applied to a muscle (extensor) with *intact nerve supply*, the muscle instead of elongating, actively contracts against the pull. *The contraction is proportional to the degree of stretch and is maintained as long as the stretch is kept up. This is called* **stretch reflex.** That it is a reflex action is further proved by the fact that, section of corresponding posterior roots abolishes it. The postural reflexes belong to this class.

Importance of stretch reflex. This is the chief mechanism for the *production of muscle tone* and *maintenance of posture.* In erect posture, gravity tends to flex the hip, knee and ankle. This slight initial flexion, stretches the antagonistic extensors, causing their contraction. Due to this contraction the subject remains standing.

The **salient features of stretch reflexes** are as follows:

1. Stretch reflexes are seen in the *antigravity extensor muscles only and not in the flexors.*
2. The stimulus arises by the stretch of the muscle and is received by the kinaesthetic stretch receptors in it.
3. The stretch receptors generate and send off series of impulses continually along the afferent fibres when the muscles are stretched. As the degree of stretch increases, more receptors are affected, the frequency of afferent impulses rises and, hence, more and more motor units are recruited into action. Consequently, more contraction is generated in the muscle. In this way, the degree of stretch and contraction become proportional.
4. *Stretch receptors do not undergo rapid adaptation* and consequently generate impulses so long as the stretch is kept up. This is in great contrast with other types of receptors.
5. The rate of discharge of motoneurones is slow, about 9 per second. This explains absence of fatigue in posturing muscles.
6. Stretch reflexes are mediated by *simple reflex arcs* (monosynaptic). Hence, their latent periods are short (0·5 msec.) and there is very little after-discharge (because of very few synapses).
7. It only takes place in the affected muscles and does not spread to any other (i.e., no irradiation).
8. They can be inhibited by evoking an antagonistic reflex.

Electrophysiology of spinal reflexes

By electrically stimulating the dorsal nerve root and correspondingly recording the changes in electrical activity from the ventral root, the properties of a reflex arc can be studied. The electrical responses that are recorded from the ventral root following stimulation of the dorsal root are considered as reflex responses. The ventral root responses elicited by dorsal root stimulation may occur through the activation of more than

one synapse. If the response occurs through the involvement of one synapse then it is called monosynaptic (Fig. 5.94) and if it occurs through the involvement of more than one synapse is called multisynaptic or (plurisynaptic (Fig. 5.95). If a nerve from a muscle is stimulated and the

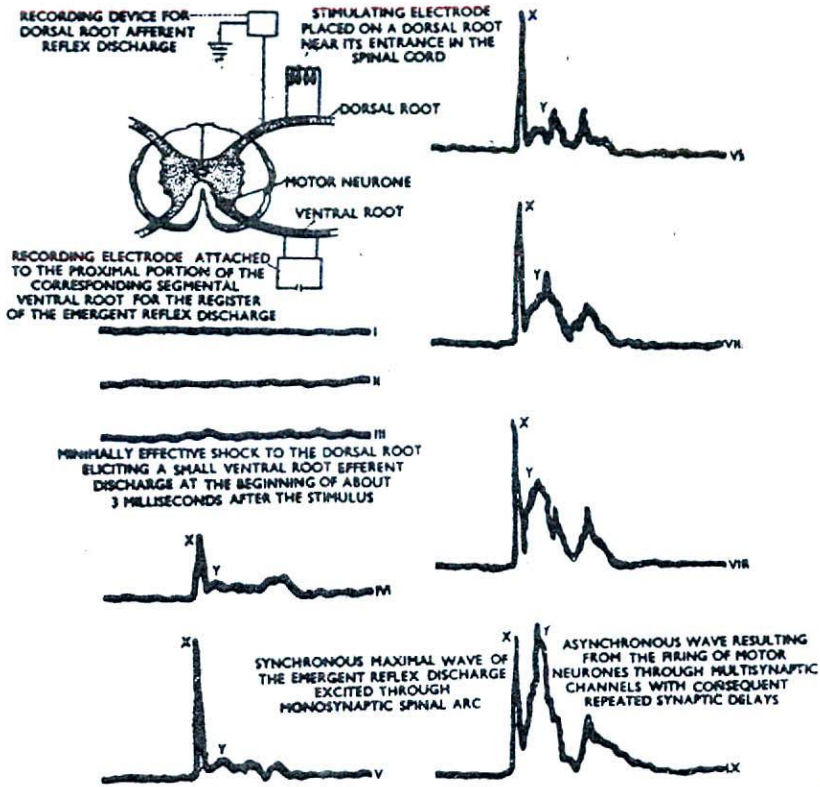


Fig. 5.93. Diagrammatic representation of spinal reflex discharges due to stimulation of dorsal spinal root at varying current strength. With the increase in shock strength, the amplitude of synchronous (monosynaptic) discharge '*X*' rises maximally in '*V*' in comparison with '*IV*', but there is little change in '*X*' with further increase of shock strength. On the other hand, the amplitude in asynchronous (multisynaptic) discharges rises slowly with the increase of stimulus strength when the synchronous (monosynaptic) discharge has attained its maximal peak (*V-IX*).

ventral root discharge is simultaneously recorded, then two responses are observed to be present in the discharge (Fig. 5.93). A minimal effective shock to the dorsal root causes a small ventral root discharge (III) which begins 3 msec. after the stimulus. As the stimulus strength is increased, two responses are observed to occur in the discharge. The early large synchronous part of the discharge 'X' increases rapidly to a maximal value which remains unchanged with further increase of stimulus strength. The early part of discharge is presumably the effect of motoneurone discharge through monosynaptic reflex pathways. The later asynchronous

part of the discharge is due to the firing of the motoneurones through the polysynaptic reflex pathways (FIG.5.93).

Monosynaptic reflex. Monosynaptic reflexes are elicited by stimulation of large afferent fibres—Ia originating from the muscle spindle of extensor and flexor muscles and having conduction velocity of about 70–120 m/sec. and diameter of 12–20 μ. If the latency of the reflex is measured then it will be observed that the shortest latency is being around 0·5 msec. which is a delay corresponding to the time necessary to traverse only one synapse (FIG.5.94). Monosynaptic discharges occupy the efferent fibres of the muscle nerve in which the afferent discharge originates. Furthermore, monosynaptic discharge returns to the muscle from which the afferent volley* originates.

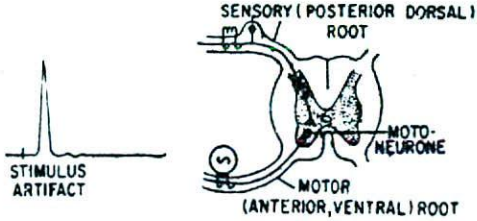


FIG. 5.94. It shows the monosynaptic reflex arc (*right*) and also monosynaptic reflex response (*left*). Monosynaptic reflex response is observed after stimulation of the Group Ia afferent fibres of the gastrocnemius nerve.

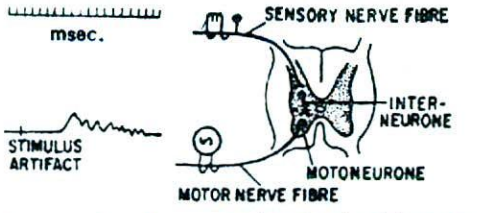


FIG. 5.95. It represents the polysynaptic reflex arc (*right*) and reflex response (*left*). Polysynaptic reflex response observed after stimulation of the cutaneous nerve (only two neurones are shown).

Polysynaptic reflex. Polysynaptic reflexes are involved with more than one synapse and hence the name. The reflex pathways may go through 2, 3, 4 or more synapses (FIG. 5.95). Many interneurones are involved in these reflexes, that is motoneurone is not stimulated directly but indirectly through the different interneurones. The afferent nerves involved in polysynaptic reflex arc are the Group of II, III and IV fibres.

Withdrawal reflexes

Withdrawal reflex in the human can be elicited from the leg of a healthy subject by a painful stimulus applied to the skin. Kugelberg, Eklund and Grimby (1960) have shown that with the stimulus applied to the underside of the great toe the response obtained would be flexion at all joints. There are upward movement of the toes, flexion of the ankle, knee and hip and forward flexion of the trunk (FIG.5.96B). When the stimulus would be moved further back on to the sole of the foot the toes moved downwards instead of upwards, the other joints flexing as before. The similar response is observed by firmly stroking the sole of the foot. When the electrical stimulus is applied under the heel the toes again moved downwards but now the ankle be extended too, other joints again flexing. Again when the stimulus is applied on the

* A volley is the response of a nerve, not of a nerve fibre, to a single stimulus. Repetitive responses are called volleys.

buttock, the trunk, hip and ankle are extended, the knee partly flexed, and the toes moved downwards (Fig. 5.96A).

Each effect of these movements is to withdraw the stimulated point from the stimulus ; but in addition they contain components that are certainly not aprt of the withdrawal, extension of several joints and downward movement of the toes. This is due to the **irradiation of flexor response.** In a standing subject, the reflex effect of these components might be to press the toes downwards and assist to maintain standing. If the stimulus be inconsistent with effective withdrawal, this only does not take place when the stimulus is applied to a toe. Therefore it is believed that the reflex response of the human leg to the painful stimulus has dual functioning of defence with the maintenance of posture.

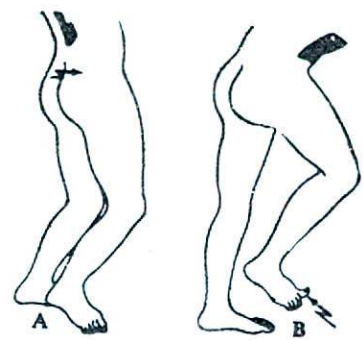


FIG. 5.96. Diagrammatic representation of the withdrawal response to painful stimuli applied to the buttock in A and to the underside of the great toe in B. Shaded areas depict the contractile trunk muscle.

If the corticospinal motor tracts from the brain, without which the human cannot stand, be damaged, components of the withdrawal response which appear to assist standing disappear. Electrical stimulus to the sole of foot in such cases has produced exactly the similar response, viz., upgoing movement of the toes and flexion at all other joints, as stimulation of the underside of the toe in a healthy subject. Firm stroking of the sole in such patients also produces an upward movement of the toes. **In infants,** before they begin to stand up and before the corticospinal tracts receive their myelin, sheath have got the same response.

In a spinal man if an upward movement of the great toe be accompanied by the flexion of the leg, this will be one of the first reflexes to appear during recovery from the spinal shock.

The response of the great toe to a firm stroke on the sole with a blunt point (the so-called *plantar* response) has great importance in clinical diagnosis, as an upward movement of the big toe is usually the first unequivocal evidence of disease of the motor pathways. This sign was first described by babinski in 1896.

An upgoing great to belongs to part of the general flexion reflex of the limb, but, although morphologically a movement of flexion, anatomically it is extention. Hence neurologists describe an upgoing movement of the great toe as an **extensor plantar response.** A healthy plantar response is terned as **flexor.**

Motor unit and Electromyogram (EMG)

One motoneurone and its axon supply not only muscle fibre but a quite number of muscle fibres. The muscle fibre supplied by one motoneurone through its single axon together with branches is called **motor unit** (Fig. 5.97A). The number of muscle fibres in a motor unit varies. In cat's leg muscle it has been observed 120-165 fibres in one motor unit.

EMG. Motor unit activity can be recorded by inserting *coaxial electrode* (FIG.5.97B) into the muscles to be studied. The electrodes then connected

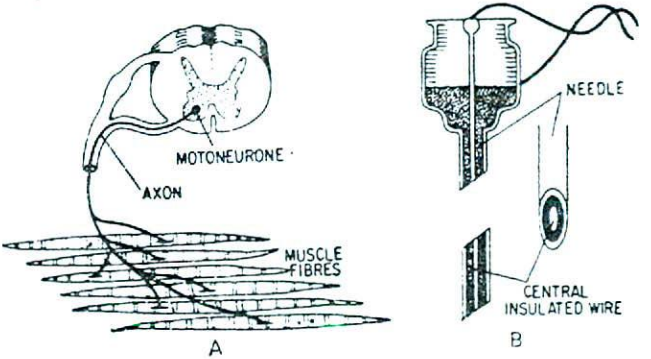
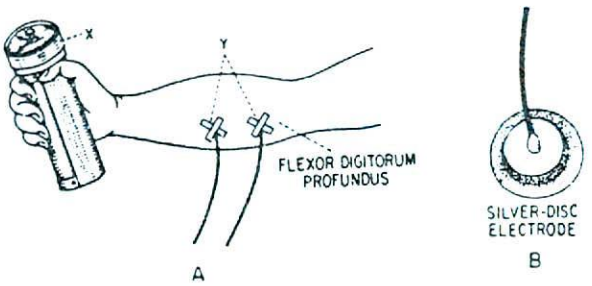


FIG. 5.97. A = The anatomical organisation of a motor unit showing one motoneurone and its axon to innervate certain muscle fibres. B = The coaxial deep needle electrode.



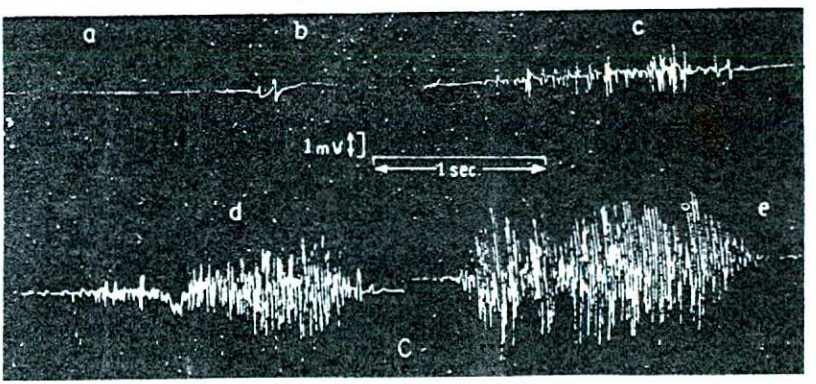


FIG. 5.98. A = Showing the recording of EMG from flexor digitorum profundus with the help of surface electrodes (y). The muscle was activated by a dynamometer (x). B = Shape of a silver-disc (surface) electrode. C = Electromyograms recorded from flexor digitorum profundus through surface electrode at different work-loads given by dynamometer; a = rest, b = at 10 Kg, c = at 20 Kg, d = 30 Kg, (e) = 38 Kg (maximum capacity of the individual). By courtesy of *Dr. (Mrs.) J. Koley*, Department of Physiology, Calcutta University.

to the electromyograph and record that is obtained during muscular activity is known as **electromyogram** (FIG.5.98C). Coaxial electrode can be made from a *hypodermic needle* by introducing an insulated inner wire within it (FIG.5.98B). Potential differences are recorded from a small volume of muscle in the immediate neighbourhood of the needle tip. Thus most of the electrical activity is from the active fibres near the electrode. Sometimes surface electrodes are used instead of coaxial deep muscle electrode. In such method of recording two surface electrodes are placed over the skin at a reasonable distance over the muscle to be studied (FIG.5.98A).

During rest of the muscle there is no action potential recorded (FIG. 5.98C–a), but as soon as the muscle becomes active, potentials are recorded (FIG. 5.97C–b-e). The potential recorded during activity is the resultant of the asynchronous discharge of motor units in the vicinity of electrodes. With minimal voluntary activity, a few number of motor units discharge and with increasing voluntary effort more and more units are brought into action. This is known as **recruitment of motor unit.** Gradation of muscular activity is a part of function of a number of motor units activated. Electromyographic studies have got clinical importance in diagnosis of motor unit disorders including peripheral nerve injuries, neuromuscular disorders such as the myotonia and myasthenia gravis, etc.

SENSATIONS

(SUPPLY OF INFORMATION TO CENTRAL NERVOUS SYSTEM)

Definition—Sensations are *feelings* aroused by change of environment. If the organism has to fight for its existence, it must be kept informed about the various events in and around it. The different ways by which the

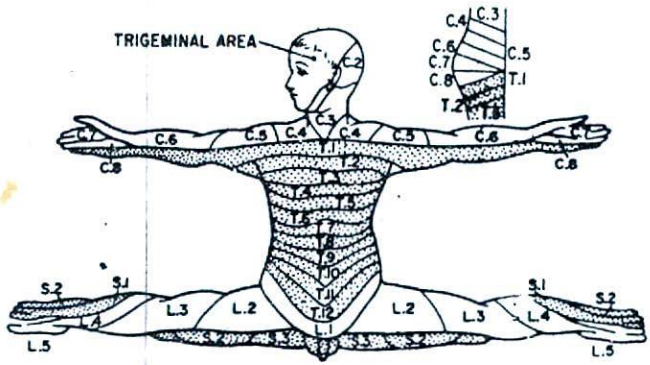


FIG. 5.99. Segmental arrangements of dermatomes. The inset shows the scheme of migration of metameres during development C. = cervical, T. = thoracic, L. = lumbar, S. = sacral (*from Strong and Elwyn, after Luciani*).

organism may be aware of its surroundings are called *sensations*. **Sensory units**—The area supplied by one sensory fibre is called a sensory unit. [Motor Unit—*vide* page 5-90).] **Dermatome** (FIG.5.99)—The area of skin supplied by one posterior root. Dermatomes for all sensory roots have been mapped out by the following methods: (*a*) *Anaesthetic zone*—cutting a posterior root and noting the corresponding anaesthetic zone on the skin.

Not perfect. Because, adjoining nerves overlap (Fig.5.100). (*b*) *Residual sensation*—cutting posterior roots above and below, and noting the

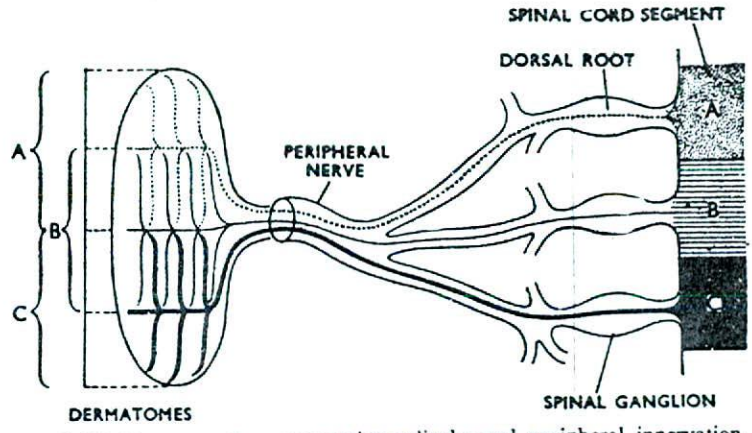


Fig.5.100.Diagrammatic representation radicular and peripheral innervation of cutaneous areas showing overlapping of nerve fibres in the dermatomes.

residual sensory area. (*c*) *Vasodilatation*—stimulation of the peripheral end of the cut posterior root causes cutaneous vasodilatation of the corresponding area.

Sensory mechanism

For each sensation the following mechanism is involved:

(*a*) An appropriate stimulus, (*b*) a specific nerve ending—selectively sensitive to that stimulus, (*c*) the sensory pathway—which carries the impulse to the central nervous system, (*d*) the nerve centre—where the impulse is finally interpreted as a particular sensation, (*e*) psychical centre—where the 'meaning' of the sensation is analysed and understood.

Properties of sensations

Sensations differ from one another in various respects—modality, quality, intensity, adaptation, duration, and localisation or projection.

1. **Modality.** The ability to distinguish the characteristic of a sensation from all other sensations is known as its *modality*. Sensations aroused by stimulation of sense organs, viz., the eye or ear, bear no resemblance to each other; to most people it is inconceivable that the stimulation of the eyes could evoke the sensation of taste or hearing. The nature of modality is not determined by the manner in which the sense organ is stimulated. As for example, when the eye is turned strongly nasalward and gentle pressure with a finger-tip is exerted upon the eyeball a luminous cycle is seen.

The modality of a sensation aroused by the stimulation of a given sense organ is fixed—Mueller's law or law of specific nerve energies.

2. **Quality** means the nature of sensation. Sensations of the same modality may vary in quality. Thus we speak of a warm or cold breeze and of a red or green light. Quality depends on (*a*) the nature of receptor stimulated (peripheral analyser or surface detector), and (*b*) the central interpretation. For instance, some individuals cannot distinguish between red and green (colour blindness) and there is also tone deafness.

3. **Intensity.** It denotes the degree of sensation. Depends on the *frequency of afferent impulses* passing up the sensory nerve. Stronger the stimulus, higher will be frequency and more intense will be the wensation.

Two sensations of the same quality may differe in intensity. A warm object delivers little energey and a hot object delivers much energy to the receptors. Sensations cannot be measured quantitatively, but sensations of the same modality and quality may be compared as to their intensity ; even this comparison is qualitative, because it is difficult to say that one sensation is twice as great as another. Although the intensity of a sensation cannot be measured, the strength of stimulus evoking the sensation can generally be stated quantitatively. Weber discovered the relationship between the ability to detect and increase or decrease in the intensity of a sensation and an increase or decrease in the strength of a stimulus. *Weber's law* states that *the least perceptible increase in the intensity of a stimulus is a constant fraction of the original stimulus.* But Weber's law does not apply to weak or very strong stimulus. The smallest variation in the strength of the stimulus which is just sufficient to produce an appreaciable variation of sensations, always bears a constant ratio to the total strength of the stimulus.

For instance, if difference can be appreciated between 20 gm and 21 gm (i.e., 1/20), then a weight of at least 10 gm has to be added upon 200 gm to make any appreciable difference. The ratio varies with the type of sensations, viz., for light 1/100 ; for cutaneous pressure 1/30 – 1/10; for weight 1/70 – 1/40

4. **Adaptation.** It will be recalled that the structures of muscles and nerves adapt to a constant stimulus. The frequency of impulses gradually decreases due to adaptation. It has been stated that the speed with which adaptation sets in differs in various receptors. For instance, a slight bending of a hair causes a distinct sensation, but, if the hair is kept in this new position the sensation quickly disappears. This is true for touch in general. The adaptation to pain sensation is exceedingly slow or absent.

5. **Extent.** It indicates the area from which the sensation arises. Depends upon the number of receptors simultaneously stimulated.

6 **Duration.** It is self-evident that a sensation occupies a certain length of time. However, a sensation is not necessarily coexistent with the stimulus. The duration of a sensation may be shorter than that of a stimulation because of adaptation. On the other hand, sensations may outlast the period of stimulation and thereby give rise to after-sensation.

7. **Localisation or projection.** It is the ability *to locate* the exact spot from which the sensation arises. Sensations are concerned more intimately with the brain than with any other part of the body. Yet when a sensation is experienced we are never conscious of our brain. Sensations are invariably projected or referred either to some part of our own body or to some part of the environment. The sensation of hunger is believed to be situated in a certain region of our own body and is not projected externally. The sensation of heat is associated with the hot object, but the pain on touching this object is always referred to that part of the body affected by the heat. Sensations of thirst, nausea, sex, equilibrium, muscle sense (proprioceptive impressions from muscles and joints), fatigue, tickling, itching, etc. On touching a warm or cold object, sensations are projected externally, but if the air around us cools our feet or if the face burns as in a fever, we think of our feet or face and not

of the environment. Most of our sensations, particularly those that are sometimes designated as special sensations, would be no value to us unless proper projection accompanied them.

Localisation shows a number of curious phenomena—(*a*) *Accuracy*—It is most accurate with cutaneous sensations; less with deep sensations (somatic) and least with the visceral sensations (autonomic). (*b*) *Sensory irradiation*—With a strong stimulus the sensation will irradiate to a wider area beyond the stimulated spot. (*c*) *Referred sensation*—Here the sensation is localised at a spot far away from its origin.

Stereognosis. Although it has a large cortical component, it can be regarded as the attribute of perceiving and understanding the form and nature of objects by means of intact touch and pressure sensation without looking at them.

CLASSIFICATION OF SENSATIONS

I. **General sensations.** Three divisions: (A) **superficial,** (B) **deep,** (C) **visceral.**

II. **Special senses—taste, smell, vision, hearing** (*vide* under the chapter of 'Special Senses').

A. **Superficial sensations**

(*i*) **Characters.** (*a*) Arises from the skin, (*b*) localisation accurate, (*c*) adaptation quick.

(*ii*) **Distribution.** Two forms: (*a*) *Punctiform,* viz., touch spots, heat spots, cold spots, etc. (*b*) *Diffuse*—sensation spread diffusely in between the spots.

(*iii*) **Parts.** Two parts: **epicritic** (discriminative), **protopathic** (crude).

Epicritic and Protopathic sensations. Head and his coworkers studied the recovery of superficial sensations after section and regeneration of cutaneous nerves. The sensations reappear in two stages. Accordingly they have been divided into two parts: **protopathic** and **epicritic.**

The **protopathic sensations** *are the crude parts of the various cutaneous sensations.* They reappear early, starting after 8 weeks and completing by 30 weeks. The localisation is inaccurate, stimulus threshold high, distribution punctiform, i.e., limited to touch spots, heat spots, etc. Intervening areas are insensitive. Types of protopathic sensations are described above.

Epicritic sensations *represent the finer discriminative aspects of cutaneous sensations.* They reappear much later and start coming after about one year. The exact time depends upon the length of the nerve involved. In the case of a long nerve it may take as much as two years. Localisation accurate, stimulus threshold low, finer discrimination possible, distribution uniform. The different types are described above.

(*iv*) **Varieties.** (1) **Touch,** (2) **temperature**—including **heat** and **cold,** (3) **pain.**

Touch

(*a*) *Adequate stimulus*—light contact, (*b*) *End organs*—Meissner's corpuscles, Merkel's discs and free nerve terminals (specially rich around the hair roots), (*c*) *Fibres concerned*—carried by thicker myelinated fibres, (*d*) *Action potentials*—large, (*e*) *Localisation*—accurate, (*f*) *Adaptation*—quick, (*g*) *Parts*—two parts: (*i*) **epicritic,** and (*ii*) **protopathic.**

Epicritic touch includes:

1. *Light touch*—tested with cotton-wool, *von Frey's* hair, etc.

2. *Tactile localisation*—the ability to tell more or less accurately which part of the skin is touched. Tested with Aesthesiometer.

In our brain there is a field corresponding to the field of the periphery of our body exposed to the environment. Normally if two widely separated areas of the skin are simultaneously stimulated by two discrete objects, two sensations are experienced. When these two areas are brought into close proximity to each other so that they can be simultaneously stimulated by one object, two distinct objects are felt. This is done in Aristotle's experiment (FIG. 5.101).where the middle finger is crossed over the index finger and the point of a blunt pencil is moved along the crotch.



FIG 5.101. Aristotle's experiment.

3. *Tactile discrimination*—the ability to recognise touch at two points. Tested with *Weber's compass*. There must be a minimum distance between the two compass points to recognise **two-point touch.** The distance varies according to the site and motility of the part. Greater the motility, lesser the distance. Such as, tip of tongue 1·1 mm, finger-tip 2·3 mm, palm 11·3 mm, back, upper arm, thigh 67·1 mm., etc.

Protopathic touch includes: (1) Crude touch or pressure (Deformity)—tested with different weights.

Temperature sensations

Varieties. There are two varieties: (*a*) **cold,** and (*b*) **heat.** These are two distinct sensations received by two different kinds of end organs (*vide* page 5-68). Cold spots are more numerous than heat spots (FIG. 5.102).In the conjunctiva there are cold spots only. Menthol stimulates cold endings. *Adaptation* of thermal sensation is fairly quick. **Three-basin test:** One hand is placed in hot water and the other hand into cold water for a short time. Then both the hands are dipped in tepid water. The former now feels 'cold', the latter 'warm'.

Parts. Two parts: **epicritic** and **protopathic.** (*a*) *Epicritic thermal sense* includes the ability to recognise small variations of temperature between 24°C. and 38°C. A subject whose epicritic thermal sense is lost, will not be able to recognise any difference of temperature within this range. (*b*) *Protopathic thermal sense*—The subject will feel cold below 24°C. and warm above 38°C. In between, no difference can be felt.

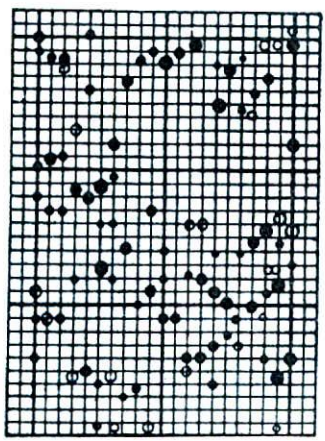


FIG. 5.102. Distribution of *cold* and *heat* spots. *Dark dots*—cold spots; *circles*—heat spots. To be noted that, cold spots are more numerous than heat spots (*after Halliburton's*).

Pain sensations—discussed below.

B. **Deep sensations.** (*a*) **Origin**—Arise from deeper structures, supplied by somatic nerves. (*b*) **Localisation**—

Inaccurate and often *referred*. (*c*) **Adaptation**—Much delayed. (*d*) **Varieties**—(*i*) *Kinaesthetic*, (*ii*) *Vibration sense*, (*iii*) *Deep pain* (*vide* page 5-98)., (*iv*) *Labyrinthine* (*vide* Vestibular apparatus).

1. **Kinaesthetic** (Proprioceptive). It is the ability to recognise the degree of movement and position of the muscles and limbs. *Origin*—from muscles, tendons, joints, bones, ligaments, etc. *End organs*—Muscle spindles, Golgi bodies, Pacinian corpuscles, etc. *Stimulus*—gross structural deformity and stretch. These sensations are very important for posture, muscle tone and equilibrium.

2. **Vibration sense.** Tested by placing the handle of a vibrating tuning fork on the part. [*It is probably same as 'kinaesthetic sensation'*.] Because, it persists even after section of the cutaneous nerves but not after the posterior roots.

C. **Visceral sensations.** The activities of the viscera, supplied with autonomics (FIG 5.103 are generally unconscious. Under abnormal conditions, only the following sensations may arise: (1) Visceral pain (*vide* page 5-98)., (2) Extremes of heat and cold, viz., in oesophagus, stomach and rectum, (3) A feeling of distention and tightness—stomach, bladder, etc. Other sensations are absent in the viscera.

Pain

Pain is probably the most fundamental and primitive sensation. Distributed more or less all over the body. It is protective in nature and always indicates some serious trouble in the locality, such as a structural damage or some sort of serious functional or metabolic derangement.

Naked nerve endings are presumably the sense organs for pain and are distributed all over the body. Pain sensations are transmitted by two types of fibres—slow fibres and fast fibres. The slow fibres are unmyelinated d.r.C (dorsal root C) fibres having slow rate of conduction (0·5–2 m/sec.) and diameter of 0·4–1·2 μm. Due to its slow conduction velocity, the C types of fibres are generally called as slow fibres. The fast fibres are the small myelinated A-δ fibres having diameter of 2–5 μm, conduction velocity at the rate of 12–30 m/sec. Having higher conduction velocity than that of the d.r.C types of fibres, these fibres are generally called as fast fibres.

According to the presence of separate types of pain fibres and also of different conduction velocity pain has been classified in two—slow and fast. Slow pain is carried by the d.r.C fibres whereas the fast pain is carried by the A-δ fibres.

Specificity of pain receptors. Morphological structures of the end organs subserving pain sensations are not clear. There are, however, evidences suggesting that these are modality specific. Pain is not produced by overstimulation of other receptors. Possibly there are specific receptors for subserving pain sensation by specific pain stimulus, i.e., some respond to thermal, others to mechanical and still others respond to chemical stimulation. Recently the presence of a specific chemosensory pain mechanism in the human skin has been described by Dash and Despande (1971).* The following varieties of pain are briefly described below.

* Paper presented in the Satellite Symposium of 29th International Congress of Physiological Sciences, West Germany, 1971.

Superficial pain. (1) **Effective stimulus**—structural damage. (2) **Nerve endings**—free terminals. (3) **Distribution**—both punctiform and diffuse. More uniformly distributed than other sensations. (4) **Localisation**—fairly accurate but often irradiates (Nocifensor system).* (5) **Varieties**—two varieties: (*a*) **epicritic,** and (*b*) **protopathic.**

Epicritic pain has the following characters: (*a*) The stimulus is lighter (low threshold). (*b*) Localisation accurate, so that finer discriminations possible. (*c*) Distribution—uniformly diffuse. **Protopathic pain** has the following peculiarities: (*a*) The threshold is high. A stronger stimulus is required to arouse pain sensation. (*b*) Reaction is excessive. The same stimulus will cause greater pain here, than on a normal spot. (*c*) Localisation inaccurate. (*d*) Distribution punctiform, i.e., not uniform. In certain areas, only protopathic pain is present, such as glans penis.

Deep pain. (1) Arises from deep somatic structures, such as muscles, tendons, ligaments, joints, bones, etc. (2) Effective stimulus—ischaemia, injury, etc. (3) Localisation—fairly accurate (accompanied by increased tone of the muscle, hyperaesthesia and vasodilatation of the overlying skin). Nearer the surface, greater the accuracy of localisation. (4) Quality of deep pain varies according to the site. Lewis recognises several varieties, viz., muscle pain, tendon pain, etc.

Visceral pain. This is the chief sensation present in the viscera. It is poorly localised, unpleasant, associated with nausea and autonomic symptoms. These pain sensations are radiated to other areas. Generally, the afferent impulses from viscera

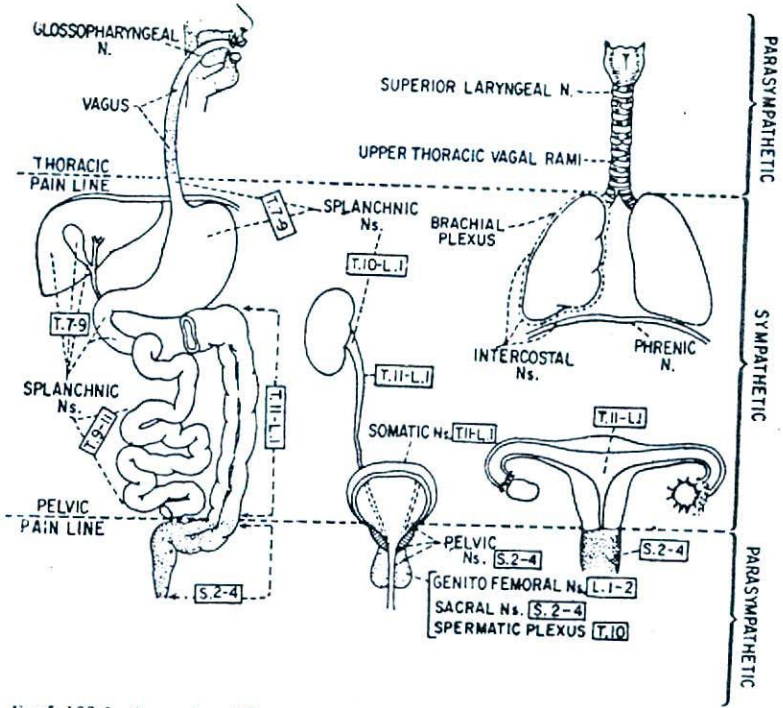


FIG. 5.103. It shows the different afferent autonomic pathways for carrying sensations from the viscera.

* **Nocifensor system.** Injury to the skin (pin-prick, strong Faradic current, etc.) produces an area of **hyperalgesia** around the injured spot. The area gradually spreads. The intensity of tenderness reaches maximum in about 15–30 minutes. According to Lewis this spreading area of hyperalgesia is due to the stimulation of a local nerve network in the skin—distinct from somatic or autonomic nerves—called by him as the *nocifensor system*. Resembles 'Flare' and is due to axon reflex.

are unconscious. But under abnormal conditions pain sensation may be felt. *Visceral pain has the following peculiarities :* (1) **effective stimulus** – may be of different types, such as increased tension, strong irregular contractions, sudden ischaemia, etc. Cutting, burning, crushing, piercing, etc., produce no pain. (2) **Quality** of pain also varies, such as **gripping, shooting, aching,** etc. (3) **Localisation** is faulty and is *often referred.* If the neighbouring somatic structures are involved, localisation may be fairly accurate. **Pathways** – Visceral pain afferents from structures above the thoracic pain line and those below the pelvic line (Fig. 5.103) passes through the parasympathetic. Whereas visceral pain impulses from thoracic and abdominal viscera, i.e. visceral structures within thoracic pain line pelvic pain line, traverse exclusively through the sympathetic and the dorsal roots of spinal nerves from T. 1-S.2. Sympathectomy effectively abolished the pain sensation from the heart, stomach and intestines. Vagal afferents act as mediators for pain impulses from the oesophagus, trachea and pharynx.

Gating of pain :

Simulataneous stimuli coming from large sensory fibres a such as tactile fibres, reduce the transmission of pain signals. This is because dorsal horns of spinal cord act as "gates" which control the entry of pain signals in presence of excessive tactile signals.

Referred pain

Pain arising from the viscera is often referred to that region of body surface which is supplied by the posterior root of the same spinal segment.

Influence of dermatomal rule. As a rule pain is generally referred to an area of some embryonic segment or dermatome from which this **pain area** has been developed embryonically. As for example, heart and arm have same segmental origin. So if pain occurs in the heart, then it will be referred to the arm. Similarly testicle has migrated from the primitive urogenital ridge from which kidney and ureter also developed. Distention of ureter will cause pain the testicle.

Theories of convergence and facilitation. Besides the dermatomal rule there are several theories of the mechanism of the reffered pain. One such theory underlying the mechanism of referred pain is the **theory of convergence.** This theory holds that somatic and visceral afferents converge on the same spinothalamic neurones (Fig. 5.104). Thus if irritation occurs in the viscera, the visceral afferents are stimulated, then signal reaches the brain and pain is projected to this somatic area equally.

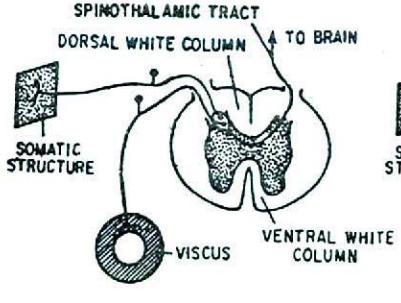


FIG. 5.104. It shows the convergence of visceral and somatic afferents on the spinothalamic neurones in the spinal cord.

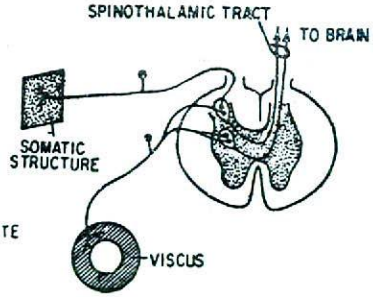


FIG. 5.105. It shows the process of facilitation in the spinothalamic neurones.

Other one is the **Theory of facilitation** (Fig. 5.105). It holds that owing to the effects of subliminal fringe, the incoming impulses from viscera lower the threshold of spinothalamic neurones receiving afferents from somatic area so that minor activity in the pain pathways from somatic areas – activity which would commonly die out in the spinal cord – passes on to the brain.

But neither the convergence nor the facilitation theory alone is responsible for referred pain. Possibly both are responsible for such pain.

Capp's study – trocar introduced into pleural, pericardial and pertioneal cavities (with effusion). A stiff blunt silver wire is passed through the trocar and different parts of the membrane stroked and sensitiveness studied. The following facts are known :

A. **Pleural sensations.** (1) **Visceral pleura** – no sensation. (2) **Parietal pleura** (supplied by intercostal nerves) – pain sensation present and is accurately localised on the overlying chest wall. (3) **Diaphragmatic pleura.** (*a*) *Central part* (phrenic – C. 3, 4, 5) – sharp pain, localised in the neck C. 3, 4 posterior roots, (*b*) *Peripheral part* (lower 6 intercostal nerves) – pain referred to regions supplied by T. 7–12 posterior

roots, viz., lower thoracic, lumbar and abdominal areas. Stronger the pain, wider will be the area referred to and may even spread to the opposite side (irradiation). Pain is associated with *tenderness* and reflex muscular rigidity (muscles supplied by the anterior horn cells of the same segment). **In actual cases of pleurisy,** same picture is seen. When parietal pleura is involved (pleural rub), pain is referred to the corresponding overlying area. In diaphragmatic pleurisy, it may be referred to the neck, chest, back or abdomen—according to the particular diaphragmatic area affected.

B. **Pericardial sensations.** (1) **Lower part of fibrous pericardium** (phrenic)—pain referred to the neck. (2) **Serous pericardium**—both visceral and parietal—no pain. Dry or effusion—produces only a feeling of tightness. (3) Pain is felt when the inflammation involves the *mediastinal* tissues (pain over the heart), or diaphragmatic pleura (over neck, back, abdomen) or in coronary occlusion (ischaemic pain).

C. **Peritoneal sensations.** (1) **Parietal peritoneum** (supplied by lower thoracic nerves). Pain felt and accurately localised on the overlying abdominal wall (with tenderness and rigidity). (2) **Visceral peritoneum**—no sensation. (3) **Diaphragmatic peritoneum**—same as diaphragm.

Cardiac pain. Typical referred pain. Sudden ischaemia gives rise to cardiac pain as in coronary thrombosis, angina, etc. Not localised in the heart, but referred to a wide area (C. 3 to T. 3), viz., neck up to jaw, sternum, left upper chest, epigastrium, inner side of the left arm, forearm and the last two fingers (associated with tenderness). A gripping sense round the chest due to spasm of intercostal muscles (*visceromotor reflex*) and increased viscerosecretory reflexes, viz., salivation, polyuria, etc. This type of ischaemic pain arises not only in heart but in other voluntary and involuntary muscles (and probably in other viscera). Lewis has shown that it is not due to anoxia, or muscular tension (or spasm) but is due to a chemical substance, the **P factor.** Lewis holds that P factor is a product of usual cellular activity and is normally washed out by circulation. During ischaemia, blood supply being inadequate, the P factor accumulates and gives rise to pain (Fig. 5.106) In acute infarction of the cardiac muscle there is formation of (1) 5-hydroxytryptamine from platelets, and (2) polypeptides which are released into the circulation and are responsible for cardiac pain.

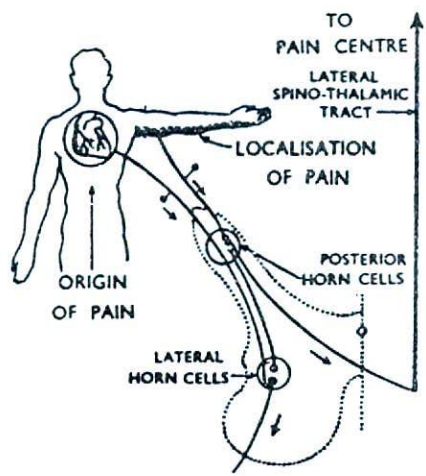


Fig 5 106. Showing nerve paths of referred pain (heart). Lateral horn cells transmits the impulse to posterior horn cells.

Causalgia. Causalgia or **heat pain** is a condition of persistent burning sensation following nerve injuries. This burning sensation is intensified due to reduction in its threshold value. But pricking sensation is not heightened. Causalgia is often associated with sweating and vasomotor changes.

Causalgia may be happened due to presence of uninsulated C fibres in the surrounding tissues and forming false synapse (ephapse) with postganglionic sympathetic fibres. Continuous discharges that pass through the sympathetic efferent fibres then set up afferent impulses in adjacent pain fibres (C nerve fibres) through **ephaptic transmission.**

Itch and tickle. Relative low-frequency stimulation of C fibres presumably produces itching sensation. Whereas tickling sensation is generally produced by very mild-frequency stimulation moved across the skin. It is suggested that the C fibre system which is responsible for itching is not the same as that responsible for pain. An itching sensation is commonly regarded as annoying and a tickling usually as pleasurable, whereas pain sensation is unpleasant. The receptors for these sensations are exclusively in the superficial layers of the skin. They are very sensitive and easily adapting.

Like pain spots, itch spot can be mapped out where many naked nerve endings of non-medullated fibres on the skin exist. Itch occurs only in the skin, the eyes and in certain mucous membrane, and does not take place in the deep tissues or viscera.

Itch is clinically important and patients may be driven to distraction by uncontrolled itching, or pruritus as it is called. The itching may be generalised, as in jaundice or some hypersensitivity reactions or it may be localised to a small area of skin. In the latter case, the cause is likely to some externally applied stimulus, in the former case to be deep to the skin. In obstructive jaundice there may be scratch marks that result from the itching which the bile salts evoke.

Itch depends upon the nerve endings in the epidermis since the sensation cannot be elicited if the epidermis is removed. The primary nerve fibres are non-medullated and ascend in the spinothalamic tract, since antero-lateral cordotomy abolishes itch as well as pain. Although the mode of activation of the receptors is not clear, but two types of comound can lead to itch when injected into the skin. These are histamine and several enzymes whose common property is that they split proteins and therefore lead to the production of kinin-like polypeptides. Several forms of dermatitis may lead to itching because of damage to skin cells with the release of histamine and/or intracellular protease enzymes. In hypersensitivity conditions an antigen-antibody reaction occurring on the surfaces of skin cells may cause the release of histamine. There are thus obvious similarities between pain and itch but whether some receptors provide information about both sensation is not clear.

In some cases there may be generalised itching without any detectable damage to the skin, apart from that due to scratching. In jaundice, diabetes and chronic nephritis there may be such a generalised pruritus. Morphine or eserine injection into the cerebrospinal fluid of cats may initiate marked scratching. In such cases, itching may be due to an action on the CNS.

Hunger. This type of sensation occurs normally at a certain time before meals and is commonly projected to the region of the stomach. It is probably due to contractions of the empty stomach, that stimulate the receptors distributed to the mucous membrane. If food is not taken in time, hunger increases in intensity for a while and is normally to cause fatigue and headache. In case of professional fasters the pangs of hunger diminish after a few days and sometimes disappear. In illness and even in case of insufficient food intake, hunger contractions may not occur at all probably resulting from a lack of muscle tone in the stomach. Whereas in diabetes or following a period of starvation hunger contractions may be frequent and severe even if an abundance of food is taken regularly.

Appetite — It is less related to physiological activity, such as stomach contractions. Hypothalamus regulates food intake and the actual

process of eating, e.g., salivation, chewing, swallowing, is concerned with many centres in the brain stem and spinal cord.

Thirst. This type of sensation is projected to the pharynx, specially the tongue. The sensory fibres of this region mediate this sense. Normal thirst sensation is termed as pharyngeal thirst probably originating from sensory impulses. Local drying from dry or salty food or dry and dusty air gives rise to a sensation of thirst, which may be soothed by moistening the membrane with a small quantity of water. Prolonged deprivation of water not only produces sensations of simple thirst alone but of actual pain and suffering Under these circumstances the sensory fibres are stimulated in many tissues and in addition the metabolism of the nervous system is directly affected by water loss.

Nausea. This sensation may be due to stimulation from the stomach, to substances in the blood or to impulses coming from the organs of vision, taste, smell, etc.

Abdominal sensations

A. Solid viscera. (1) **Liver**—pain felt if (*a*) parietal peritoneum be involved, and (*b*) in acute distention, viz., acute venous engorgement as in congestive heart failure. Slow distention—as in tumour—causes no pain. (2) **Kidney**—movable kidney or kidney with stone is painful on pressure. May be due to involvement of somatic perirenal afferents. (3) **Ureter**—strong peristalsis—painful (renal colic). Localised on the same side but referred to groin, scrotum, penis (upper lumbar nerves). (4) **Pancreas**—acute pancreatitis—pain. (5) **Spleen**—rupture causes pain, may be due to involvement of parietal peritoneum or diaphragm or other somatic structures.

B. Hollow viscera. (1) Extremes of heat and cold in oesophagus, stomach, rectum. (2) Feeling of distention and fullness in all hollow organs. (3) Pain—when tension is great or irregular strong peristalsis (colic). Always *diffuse* and localised in the midline—upper intestine (duodenum) in the upper part and lower intestine in the lower part of midline. **Biliary colic**—localised on the same side, i.e., right hypochondrium.

ARRANGEMENT OF GRAY AND WHITE MATTER IN THE SPINAL CORD

The spinal cord is a primary centre of reflex action for the trunk and limbs, and consists of the main conducting paths to and from higher centres in the spinal cord and brain. The cord may be considered as consisting of more or less autonomous segments. Each segment is related by afferent and efferent nerve fibres to its own specific segmental area of the body, as well as to the segments above and below. It is obvious from the large amount of spinal cord space devoted to ascending and descending tracts that the brain exerts an important controlling influence over the segments.

Spinal cord is symmetrically divided into *two* lateral halves, dorsally by a septum known as *posterior median septum* and ventrally by a fissure (cleft) known as *anterior median fissure* (FIG.5.107). The brief histological details are as follows:

I. **Central canal.** In the middle. Lined by cubical ciliated epithelium—the *ependyma*. Cerebrospinal fluid (C.S.F.) circulates through this canal. The central canal actually pierces through the isthmus (commissure) of the two symmetrical lateral halves of the gray matter. Parts of the gray matter in front of the central canal is known as *anterior (ventral) gray commissure* and the same on behind the central canal is known as *posterior (dorsal) gray commissure*.

II. **Gray matter.** In the form of a rough crescent one on each side. Each crescent has three parts: *anterior horn*, *lateral horn* and *posterior horn*. Gray matter is chiefly composed of three elements: (*a*) **nerve cells.**

(*b*) **neuroglia.** (*c*) **nerve fibres, dendrites** or **axons** which are mostly of unmyelinated fibres supported by a group of neuroglial cells.

(*a*) **Nerve cells.** There are three important collections of nerve cells:

1. *Anterior horn cells* (motor)—The cells are multipolar and are arranged in different groups. α- and γ-motoneurones are present. α-motoneurones innervate the *extrafusal* fibres (*vide* pages **5–68**, **71**) and γ-motoneurones innervate the *intrafusal* fibres of the muscle spindle. Renshaw cells, a group of interneurones, are present in the antero-medial part of the anterior horn cells. These cells send *antidromic inhibitory impulses* to the motoneurones. The anterior nerve root takes origin from these cells.

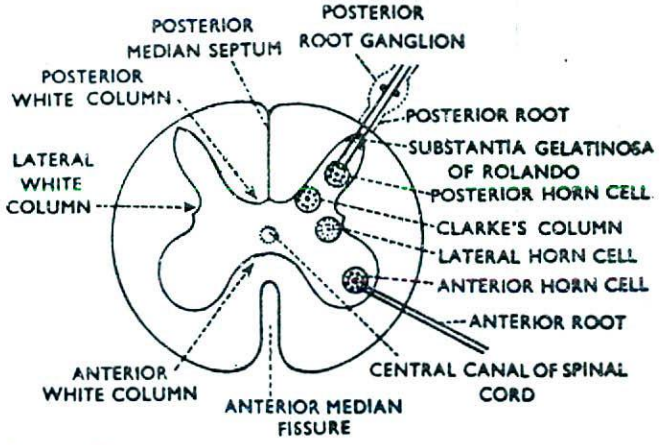


FIG 5.107 Transverse section of the spinal cord showing arrangement of gray and white matter.

2. *Posterior horn cells* (sensory)—Relay station for posterior nerve root. At the base of the posterior horn there are specialised cells known as **Clarke's column** or *dorsal nucleus*. Found only in the lower cervical, thoracic and upper lumbar regions (C. 7–L. 3). They are the relay stations for spinocerebellar fibres. At the tip of the posterior horn there are closely packed cells called **substantia gelatinosa of Rolando.** At the medial part of the posterior horn there are large round or oval nerve cells.

3. *Lateral horn cells* (autonomic)—Relay station for autonomic. Found only in the thoracic and upper lumbar regions (T. 1–L. 2). The cells are smaller than those of anterior horn cells. They are also known as **intermediolateral cell groups.** They give preganglionic sympathetic fibres and come out through the anterior spinal root.

(*b*) **Neuroglia.** There are two important collections, viz.,

1. *Substantia gelatinosa centralis*—around the central canal.
2. *Substantia gelatinosa of Rolando*—at the tip of the posterior horn.

III. **White matter.** White matters of the spinal cord surround the gray matter and consist of myelinated and unmyelinated fibres. Myelinated fibres are predominating. It has been described that the white matter is incompletely divided into symmetrical two lateral halves. The lateral half of white matter on each side is divided into three compartments, *anterior white column* (funiculus), *lateral white column* (funiculus) and

posterior white column (funiculus), by the fibres of the ventral and dorsal spinal roots. White matter in front of the gray commissure is known as *anterior* (ventral) *white commissure* and the same in behind the gray commissure is known as *posterior* (dorsal) *white commissure.* Ascending and descending tracts and transversed fibres are passing through the white matter to occupy their respective positions.

THE SPINAL NERVE

There are 31 pairs of spinal nerves (*vide* p. 5-121). The first cervical nerve originates from the medulla oblongata and leaves the spinal canal between the occipital bone and atlas. Other cervical spinal nerves arise from the spinal cord, and each leaves the spinal canal through an intervertebral foramen above the vertebra whose number it bears. The eighth spinal nerve emerges from the vertebral column below the seventh cervical vertebra. All the other spinal nerves emerge from the spinal cord below the vertebra whose number it bears. The coccygeal nerves pass from the lower extremity of the spinal canal.

Mixed nerves. Spinal nerves consist primarily of medullated nerve fibres and are named mixed nerves due to contents of motor and sensory fibres. Each spinal nerve is formed by the union of anterior and posterior roots.

1. **Anterior spinal root.** *Composed entirely of motor fibres.* They are: (*a*) the axons of anterior horn cells (somatic), (*b*) axons of the lateral horn cells (autonomic)—in the thoracic and upper lumbar regions only. The autonomic fibres represent the preganglionic fibres of sympathetic (pupil dilator, pilomotor, vasomotor, cardiac accelerator, etc.).

2. **Posterior spinal root.** *Consists of afferent fibres only.* [*Vide* page 5-121] Recent studies show that some vasodilator fibres are also present. The posterior root is composed of the axons of posterior root ganglion, and contains both somatic and autonomic fibres, as described below:

The *somatic afferents* come from the skin and deep somatic structures. *Autonomic afferents* come from the viscera. *All have their cell station in the posterior root ganglia.* The nerve fibres of posterior root are 40% non-medullated and 60% medullated. Nerve fibres have been broadly classified into three: A, B and C (*vide* p. 5-31). The A fibres (thickest) come from the touch and kinaesthetic endings. The B fibres (medium) carry thermal sensations and probably localised pain. The C fibres (thinnest) carry diffuse skin pain, ischaemic muscle pain, etc. [The motor fibres in the posterior root are believed to be vasodilator fibres of the C Group.]

Distribution of the terminal branches of spinal nerves. After leaving the spinal column, each spinal nerve mainly divides into: (*a*) the *recurrent branch* which is distributed to the meninges (hence *meningeal*), (*b*) the *ventral branch* which supplies the extremities and parts of the body wall in front of the spine, (*c*) the *dorsal branch* which supplies the muscles and skin of the back of the head, neck and trunk. Another one is the *visceral branch* which is supplied by the nerves from T. 1 to L. 3.

All these connect with the sympathetic ganglia by means of the white and gray rami fibres (Fig 5.108) which pass from the nerve to the ganglia and *vice versa.* From the sympathetic ganglia to their final distribution, the *autonomic nerves* are formed. These nerves form *cardiac, coeliac* or *solar, hypogastric, pelvic* and *enteric plexuses* (*vide* Autonomic distribution). A quite number of nerve fibres from the sympathetic ganglia return to and are

distributed with the spinal nerve to innervate sweat glands, arrector pili muscles and smooth muscles of all blood vessels.

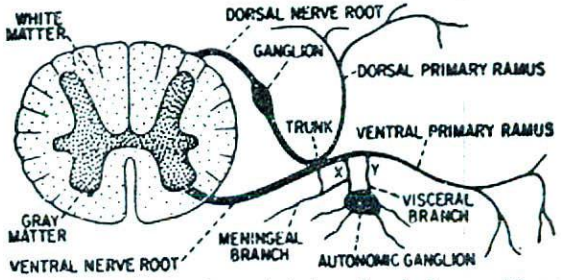


FIG.5.108 It shows branches of a typical thoracic spinal nerve (diagrammatic). X = white ramus, Y = gray ramus.

After emerging from the cord, spinal nerves form the *cervical, brachial, lumbar* and *sacral plexuses* from which the peripheral nerves are formed.

In the thoracic region there is no plexus, but the fibres pass as intercostal nerves out into the intercostal spaces to innervate intercostal muscles, upper abdominal muscles and the skin of the abdomen and chest.

Cervical plexus. The ventral rami of the four upper cervical nerves (C.1–C.4) form this plexus (FIG.5.109 A). The 2nd, 3rd and 4th nerves divide

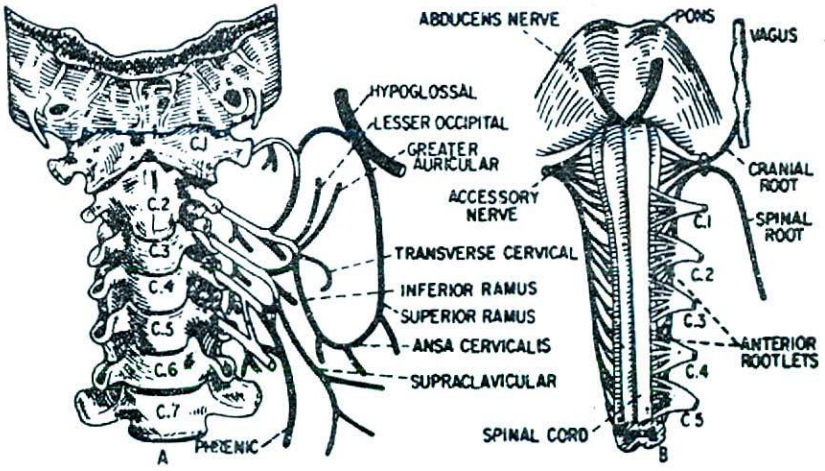


FIG 5.109.A shows the cervical plexus. The major nerves which emerge are the ansa cervicalis, phrenic and four cutaneous nerves. B represents accessory nerve. Its origin from the spinal cord and brain stem is shown at the right, and the cranial part is distributed with the vagus.

into a lower and an upper branch, these in turn unitedly form three loops from which the peripheral nerves are distributed. These cervical nerves communicate with the hypoglossal, vagus and accessory cranial nerves to muscular system of the head and neck (FIG.5.109 B).

Brachial plexus. The ventral rami of the last four cervical (C. 5-C. 8) and the first thoracic nerves form this plexus. The ventral rami

supplying this plexus give rise to (*i*) *superior trunk* (C. 5–C. 6), (*ii*) *inferior trunk* (C. 8 and T. 1), and (*iii*) *middle trunk* (C. 7). Each trunk splits into a dorsal and a ventral division. The dorsal divisions of three trunks fuse to form the *posterior cord* and the ventral divisions of the superior and middle trunks form the *lateral cord*, while the ventral division of the inferior trunk is continued as *medial cord*. Principal nerves formed are the *median* (C. 6. to T. 1, sometimes C. 5), ulnar (C. 8 and T. 1) and radial (C. 5 to T. 1) nerves which innervate the upper extremities (Fig. 5.110).

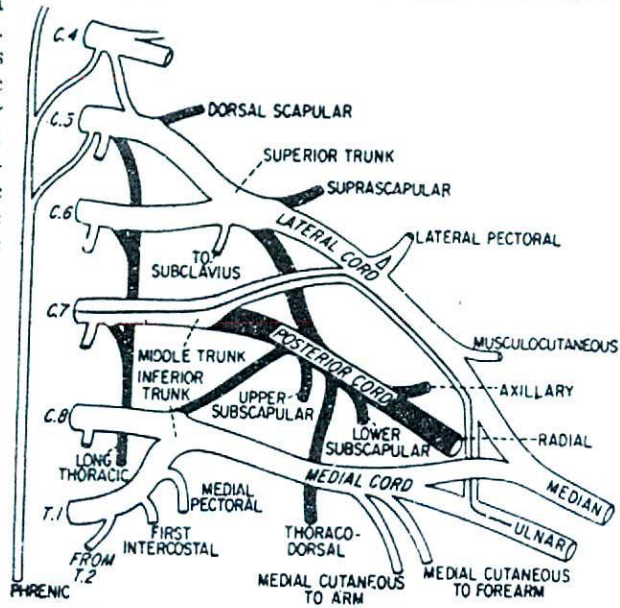


Fig. 5.110. It represents the distribution of brachial plexus. Cords and peripheral nerves formed by anterior divisions of ventral primary rami of spinal nerves are **white.** Dorsal cord and peripheral nerves formed by posterior divisions of ventral primary rami of spinal nerves are **black.**

Lumbar plexus. A few fibres of the 12th thoracic and the anterior primary division of the four upper lumbar nerves (L. 1–L. 4) form the lumbar plexus. The largest nerves formed are the femoral (L. 2–L. 4) which supplies muscles and skin on anterior aspect of the thigh and knee, and the obturator (L. 2–L. 4) which supplies adductor and obturator muscles (Fig. 5.111).

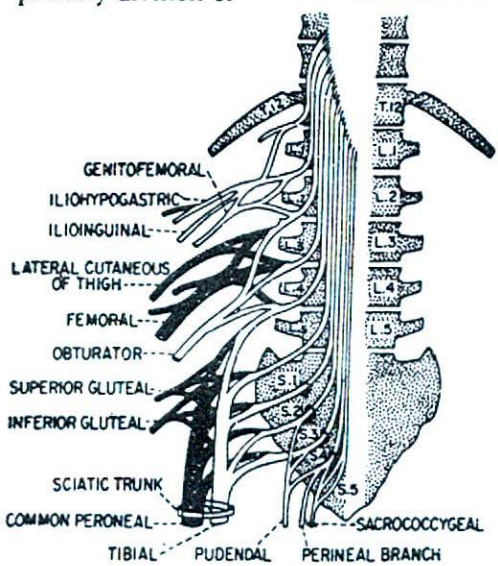


Fig. 5.111. It shows the distribution of lumbosacral plexus. Nerves to single muscles are omitted. Peripheral nerves formed by anterior divisions of ventral primary rami are **white;** nerves formed by posterior divisions of ventral primary rami are **black.**

Sacral plexus. This plexus is supplied by a few fibres from the fourth and all of the fifth lumbar nerves,

and by S. 1, S. 2 and the greater portion of S. 3. The largest nerve is the great sciatic which supplies muscles of lower extremity (FIG. 5.111).

Sacral 4 and 5 form **coccygeal plexus.**

Names of the peripheral nerves. Many of the larger branches given off from the spinal nerves bear the same name as the artery they accompany, or the part they innervate. An exception to this is the two sciatic nerves (L. 4 to S. 3), the largest nerves in the body, which pass down from the sacral plexus, one on each side of the body near the centre of each buttock and the back of each thigh region, to the popliteal region, where each splits into two large branches supplying legs and feet. Motor branches from these nerves are distributed to the muscles of the legs and feet, and sensory branches pass to the skin of the lower extremities.

THE TRACTS

Introduction. Fibres carrying different sensations enter the spinal cord through the posterior roots. Inside the cord, a rearrangement takes place. Fibres carrying one kind of impulse tend to collect into a bundle. Such bundles are called sensory tracts. Motor tracts are also formed on similar lines.

Definition. A tract may be defined as *a bundle of fibres carrying one or a group of motor or sensory impulses in the central nervous system.*

Functionally nerve tracts (fasciculi) may be grouped in each column (funiculus) into ascending (sensory), descending (motor) and intersegmental fibres (FIG. 5.112).

I. Ascending tracts (Sensory tracts):

1. Tract of Goll (Fasciculus gracilis).
2. Tract of Burdach (Fasciculus cuneatus).
3. Comma tract of Schultze (Tractus interfascicularis).
4. Dorsal spinothalamic tract (Lateral spinothalamic tract).
5. Spinotectal tract.
6. Dorsal spinocerebellar tract (Flechsig's tract).
7. Ventral spinocerebellar tract (Gower's tract).
8. Spino-olivary tract.
9. Spinoreticular tract.
10. Spinovestibular tract.
11. Spinopontine tract.
12. Spinocortical tract.
13. Ventral (anterior) spinothalamic tract.

II. Descending tracts (Motor tracts):

1. Pyramidal tracts:
   (*a*) Crossed pyramidal tract (Large lateral corticospinal tract).
   (*b*) Direct pyramidal tract (Uncrossed anterior corticospinal tract).
   (*c*) Uncrossed small lateral pyramidal (corticospinal) tract.
2. Corticobulbar tract.
3. Extrapyramidal tracts:
   (*a*) Rubrospinal tract.
   (*b*) Tectospinal tract and Tectobulbar tract
   (*c*) Reticulospinal tract.
   (*d*) Dorsal vestibulospinal tract.

(*e*) Ventral vestibulospinal tract.
(*f*) Olivospinal tract (Bulbospinal tract).
(*g*) Descending medial longitudinal fasciculus.

III. Intersegmental fibres (both ascending and descending):

1. Ground bundle of anterior column or funiculus (Anterior intersegmental or sulcomarginal fasciculus).
2. Ground bundle of lateral column or funiculus (Lateral intersegmental fasciculus).

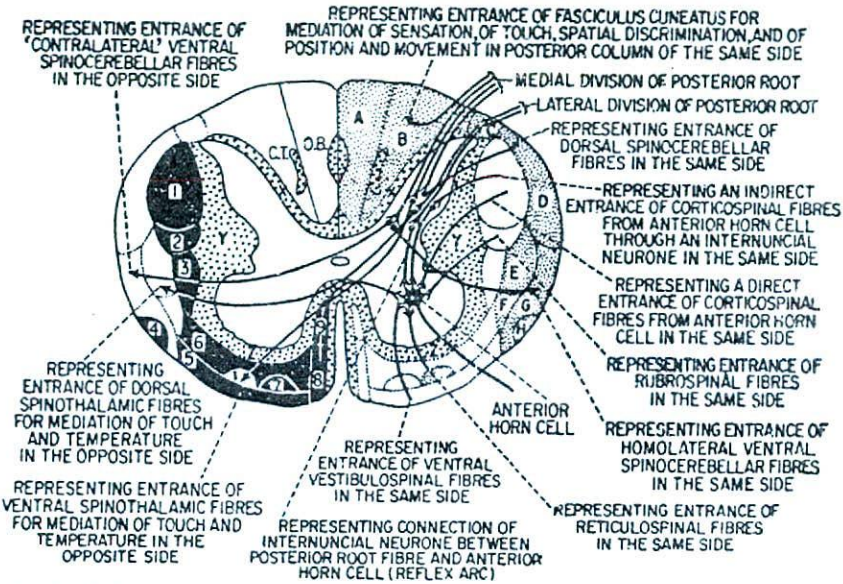


FIG. 5.112. Diagrammatic representation of cross-section of a spinal cord showing the centrally placed gray matter composed of nerve cell bodies and nerve fibres (dendrites and axons) including intersegmental fibres. Principal descending (motor) and ascending (sensory) tracts passing through the white matter of the spinal cord have also been shown.

MOTOR*	SENSORY
1 = Crossed pyramidal tract.	C.T. = Comma tract.
2 = Rubrospinal tract.	O.B. = Oval bundle.
3 = Dorsal vestibulospinal tract.	A = Tract of Goll.
4 = Olivospinal tract.	B = Tract of Burdach.
5 = Ventral vestibulospinal tract.	C = Tract of Lissaure (Fasciculus posterolateralis).
6 = Reticulospinal tract.	D = Flechsig's tract.
7 = Tectospinal tract.	E = Dorsal spinothalamic (Lateral spinothalamic) tract.
8 = Direct pyramidal tract.	F = Spinotectal tract.
9 = Medial longitudinal fasciculus.	G = Gower's tract.
	H = Spino-olivary tract.
	I = Ventral spinothalamic tract.

X = Posterior ground bundle. *Y* = Lateral ground bundle. *Z* = Anterior ground bundle (*after Best & Taylor*).

* There are some descending autonomic fibres: (*a*) Pupil-dilating fibres, (*b*) Vasomotor fibres, etc.

3. Posterior column or funiculus consists of
   (*a*) Posterior intersegmental fasciculus (Posterior ground bundle).
   (*b*) Septomarginal fasciculus:
   (*i*) Posterior septomarginal fibres (in cervical and upper thoracic segments). (*ii*) Dorsal peripheral strand (in lower thoracic segments). (*iii*) Oval bundle of Fleichsig (in lumbar segments). (*iv*) Triangular area of Phillippe-Gombault (in sacral segments).

Methods of investigation of tracts

1. **Study of myelination** (Flechsig's method). This method is based on the fact that different tracts acquire their myelin sheaths at different periods of development. The afferent tracts are myelinated first, then the efferent and lastly the association fibres. All the afferent tracts are fully myelinated before birth. Tracts of Goll and of Burdach are first myelinated. Next come the spinocerebellar tracts. The pyramidal tracts are myelinated after birth. The peripheral nerves and the nerve roots become myelinated in the fifth month of intra-uterine life.

2. **Method of degeneration** (Waller). To study the progress of degeneration after section. If the degeneration is ascending, the tract is sensory and if descending, it is usually motor (Marchi's or Weigert-Pal's stain).

3. **Physiological method.** To study the effects of section or stimulation of nerve cells or fibres in different regions.

4. **Electrical method.** To detect the passage of nerve impulses (i.e., action potentials) through the cord and their termination in the brain.

5. **Comparative physiology.** Study of tracts in the different species. The pyramidal tracts are present in the man and higher animals only.

ASCENDING TRACTS.

Sensory Tracts or Afferent Tracts

Note: From periphery to the centre, there are three neurones and two relays. For cerebral tracts, crossing takes place in the second neurone. For cerebellar tracts no crossing (*vide* page 1119). Complete description of a tract should include the following headings: *origin, situation, course, extent, number of neurones, crossing, termination* and *function.*

I. Afferent Tracts in the Posterior Column (Funiculus):
   1. **Fasciculus gracilis** (Tract of Goll).
   2. **Fasciculus cuneatus** (Tract of Burdach).
   3. **Comma tract of Schultze** (Tractus interfascicularis).

II. Afferent Tracts in the Lateral Column (Funiculus):
   1. **Dorsal spinothalamic tract** (Lateral spinothalamic tract).
   2. **Spinotectal tract.**
   3. **Flechsig's tract** (Direct or dorsal [posterior] spinocerebellar tract).
   4. **Gower's tract** (Indirect or ventral [anterior] spinocerebellar tract).
   5. **Spino-olivary tract.**
   6. **Spinoreticular tract.**
   7. **Spinovestibular tract.**
   8. **Spinopontine tract.**
   9. **Spinocortical tract.**

III. AFFERENT TRACTS IN THE ANTERIOR COLUMN (FUNICULUS):

1. **Ventral (anterior) spinothalamic tract.**

I. AFFERENT (SENSORY) TRACTS IN THE POSTERIOR COLUMN

1. **Fasciculus gracilis** (Tract of Goll) (FIGS 5.113 & 5.114).

(*a*) **Origin.** Made up of axons of the bipolar cells of the posterior root ganglia receiving afferents from *the lower half of the body.*

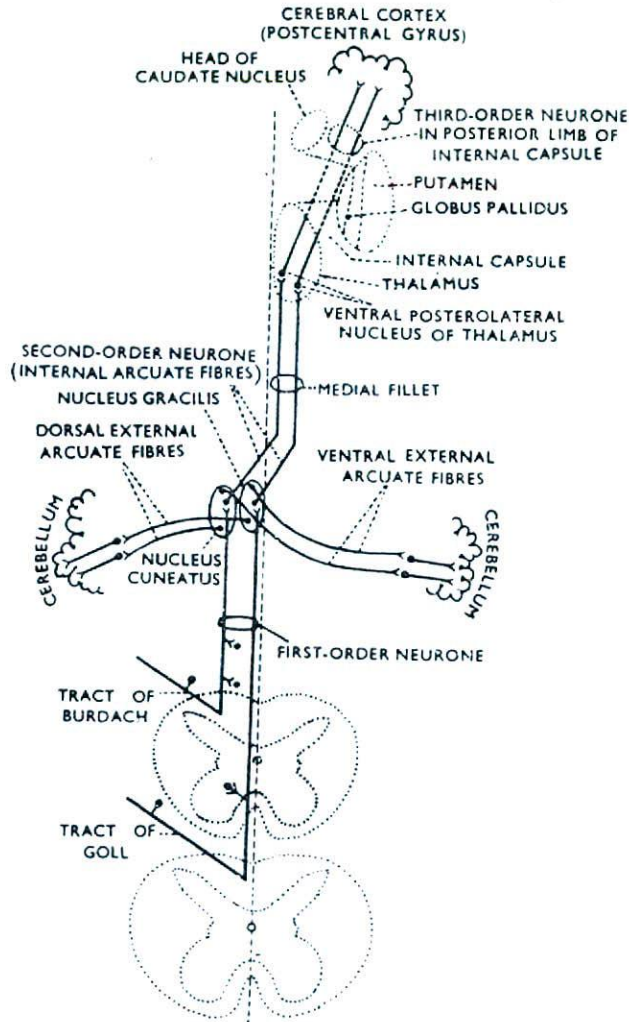


FIG 5.113 Diagrammatic representation of tracts of Goll and of Burdach (simplified).

(*b*) **Situation and extent.** After entering the spinal cord the fibres run in the posterior column and extend throughout the cord. Below the

midthoracic region it occupies the whole breadth of the posterior column; but above this level its fibres are pushed medially by the tract of Burdach.

(*c*) **Neurone, crossing and termination.** Since the fibres belong to the first-order neurone, they do not cross and remain on the same side. These fibres end in four ways: (*a*) Some fibres make reflex connections at different segments. (*b*) Some fibres end round the posterior horn cells, and then cross and join the ventral spinothalamic tract of the opposite side.

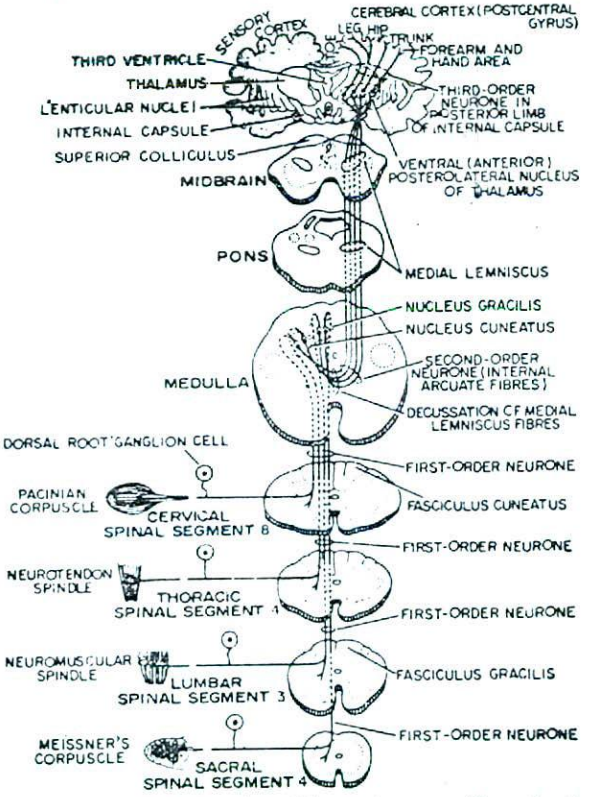


FIG. 5.114. Diagrammatic representation of internal arcuate fibres showing its origin and termination through medial lemniscus into the thalamus and thence into the cortex.

(*c*) Some fibres give descending branches which make up the **comma tract of Schultze** (Tractus interfascicularis), (*d*) Majority of the fibres end in the medulla in the **nucleus gracilis** (FIG. 5.115). Here, first relay takes place and second-order neurone arises. The axons of this neurone are divided into two groups: *External and internal arcuate fibres.* The *external arcuate fibres* are further subdivided into two groups: Dorsal and ventral external arcuate fibres —The *dorsal external group* passes through the inferior cerebellar peduncle of the same side and ends in the cerebellum. The *ventral external group* crosses to the opposite side, passes through the inferior cerebellar peduncle and ends in the cerebellum on the opposite side.

The *internal arcuate fibres*, being axons of the second-order neurone,

cross to the opposite side, enter the medial fillet or lemniscus, pass through the midbrain and end in the ventral postero-lateral nucleus of the thalamus. Here, the second relay takes place and the third-order neurone arises. The axons of this neurone pass through the posterior limb of the internal capsule and end in the postcentral gyrus (sensory cortex).

(*d*) **Functions.** This tract carries the following impulses *from the lower half of the body:* (1) Fine touch, tactile localisation and tactile discrimination. (2) Kinaesthetic sensations. (3) Sense of vibrations. (4) Some unconscious impulses (probably kinaesthetic) passing to the cerebellum through the external arcuate fibres. (5) May constitute the sensory pathway for some superficial reflexes.

2. **Fasciculus cuneatus** (Tract of Burdach) (FIG. 5.113 & 5.114). The general description, viz., course, relays, termination and functions, etc., of this tract is same as that of Goll. The following are the differences: (*a*) It is made up of posterior root fibres from the upper half of the body. (*b*) Situated laterally in the posterior column of the upper thoracic and cervical regions only. (*c*) Ends in the medulla in the **nucleus cuneatus** (lateral to nucleus gracilis) (FIG 5.115). (*d*) Carries the same sensory impulses but from the upper half of the body.

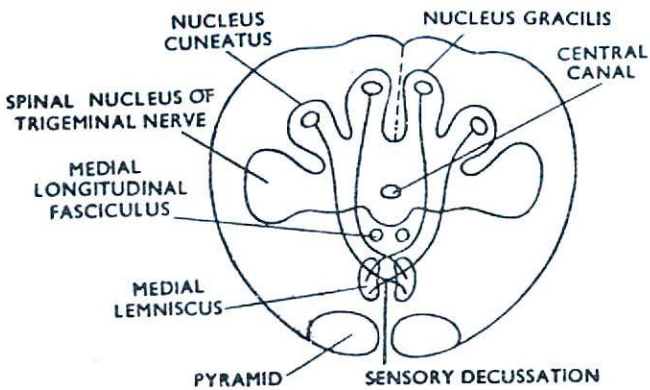


FIG 5.115. Diagrammatic representation of the transverse section of the caudal (lower) part of the medulla at the level of afferent (sensory) decussation of pyramids.

3. **Comma tract of Schultze** (Tractus interfascicularis). Made up of short descending branches derived from the tracts of Goll and of Burdach. Situated in the posterior column between these two tracts and looks like a 'comma' in transverse section.

Its **functions** are: (*a*) to establish intersegmental communication, and (*b*) to form short reflex arcs. Some workers hold that it contains motor fibres also. The peculiarity of this tract is that although sensory in function, it is descending in course.

II. AFFERENT (SENSORY) TRACTS IN THE LATERAL COLUMN

1. **Dorsal spinothalamic tract** (FIG. 5.116).

(*a*) **Origin, distribution and termination.** The dorsal spinothalamic tract (lateral spinothalamic tract) is an ascending one which occupies the *lateral column* of the white matter in the spinal cord. Some

posterior root fibres (*axons of the first-order neurone*) of all segments after entering the spinal cord end round the cells of the *substantia gelatinosa of Rolando*. These unmyelinated fibres of the posterior root are known as **tract of Lissauer** (*Fasciculus posterolateralis*). The *second-order neurone* starts from these cells. Most of the axons of second-order neurone cross in the anterior white commissure, obliquely to the opposite side of the same segment and ascend in the lateral column of the cord. Some fibres of the second-order neurone, before crossing, may ascend up one segment (not shown in Fig 5.116).and then cross in the anterior white commissure to reach the lateral column of the opposite side of the cord. This tract together with ventral (anterior) spinothalamic tract constitutes the spinal lemniscus in the medulla oblongata. The spinal lemniscus then ascends up to join the medial lemniscus in the upper part of the medulla oblongata

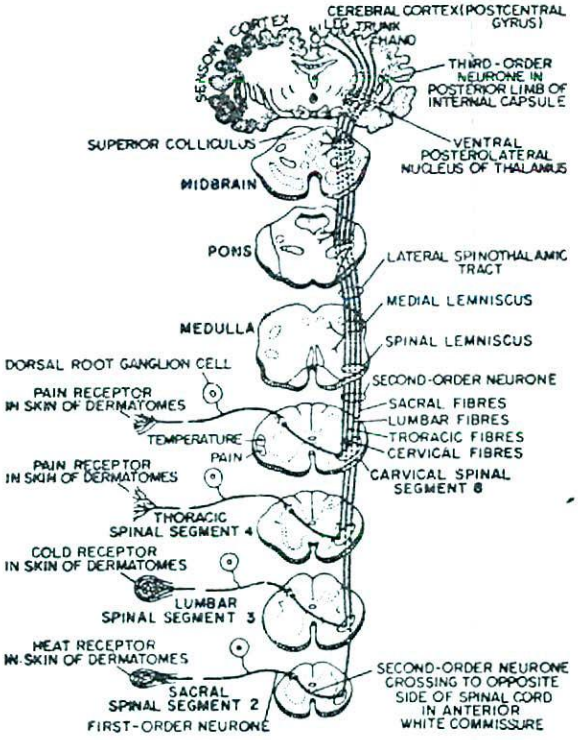


Fig 5.116.Diagrammatic representation of dorsal (lateral) spinothalamic tract.

and finally terminate in the ventral posterolateral nucleus of the thalamus. The lateral spinothalamic tract, at higher brain stem level, sends several collaterals into the reticular formation and tegmentum before ending in the thalamus. Here *third-order neurone* starts and axons of this neurone terminate in the postcentral gyrus of the cerebral cortex through the posterior limb of internal capsule.

(*b*) **Functions.** The lateral spinothalamic tract carries (1) fibres of all pain impulses. (2) All temperature impulses—both heat and cold. (3) Unilateral section of this tract causes a complete loss of pain and temperature on the opposite side of the body and owing to the oblique crossing of axons of the second-order neurone, the contralateral sensory loss extends to a level one segment below that of the lesion.

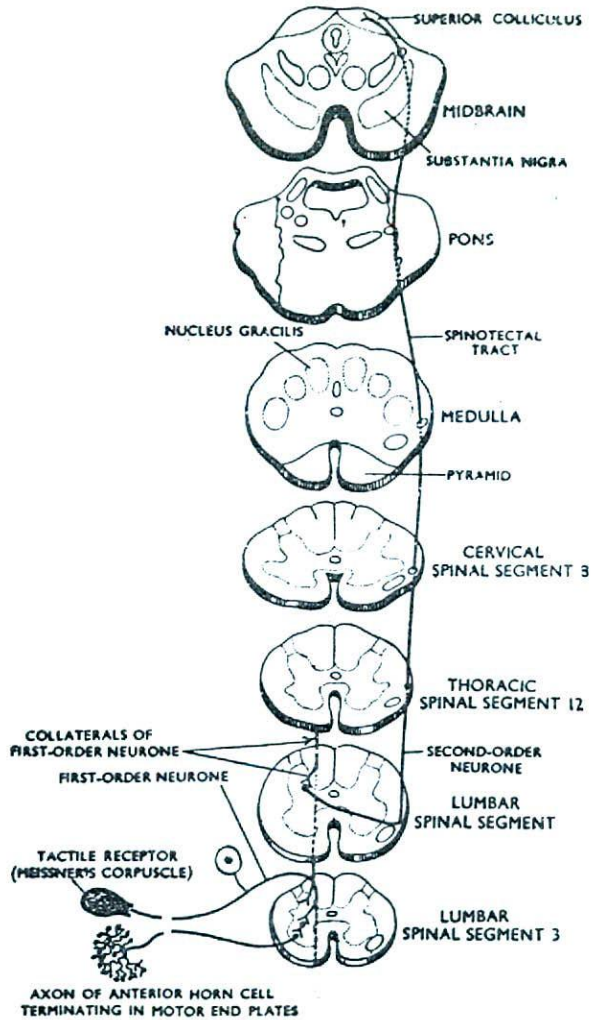


FIG 5.117 Diagrammatic representation of spinotectal tract.

2. **Spinotectal tract** (FIG. 5.117). Fibres arise from the posterior horn cells of the opposite side. Situated in this lateral column, ventral to the lateral spinothalamic tract, being most prominent in the cervical

region pass through the medial or mesial fillet or lemniscus and end in the superior colliculus (midbrain). **Functions.** *Subserves spinovisual reflexes.*

3. **Flechsig's tract** (Direct or dorsal [posterior] spinocerebellar tract) (FIG.5.118).Some fibres of the posterior root end round **Clarke's column** *of cells on the same side.* Here the second-order neurone arises and constitutes this tract. Although the second-order neurone, yet the fibres will not cross. Because they are destined for the cerebellum. The fibres bend laterally, enter the lateral white column, occupy the most peripheral part lateral to the spinothalamic tract and dorsal to Gower's tract. It extends through the upper lumbar, thoracic and cervical regions. In the medulla it enters the inferior cerebellar peduncle of the same side and ends in the vermis. Here the third-order neurone arises and passes to the cerebellar cortex. **Function**—*carries unconscious kinaesthetic impulses to the cerebellum* (essential for posture).

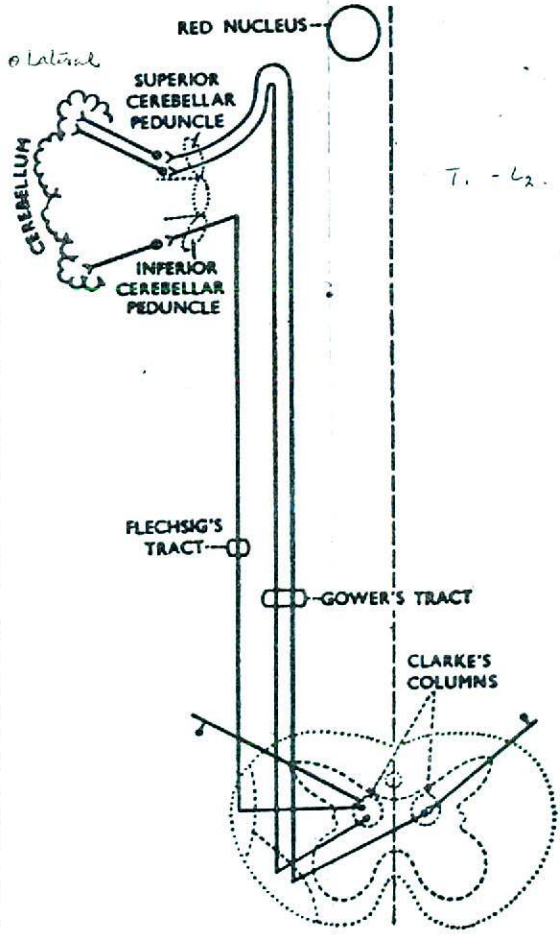


FIG 5.118 Diagrammatic representation of Flechsig's tract and of Gower's tract.

4. **Gower's tract** (Indirect or ventral [anterior] spinocerebellar tract) (FIG. 5.118). Like the above it also *carries unconscious kinaesthetic impulses to the cerebellum.* But it has the following differences with Flechsig's tract: (*a*) **Composition and origin**—It is made up of fibres *arising from Clarke's columns of both sides.* It is composed mostly of crossed and partly of uncrossed fibres. The presence of crossed fibres is an apparent violation of ipsilateral cerebellar control. (*b*) **Situation**—The tract makes its appearance first in the third lumbar region of the spinal cord and remains in the lateral white column, just ventral to Flechsig's tract. (*c*) **Course, extent and termination**—It passes through the cord and medulla, enters the midbrain and goes up to the level of the red nucleus

(without termination). Here, the fibres turn sharply backwards and downwards, and enter the superior cerebellar peduncle of the same side and end in the vermis. Smith (1961) has described that this tract initially crosses at the spinal level and at least some fibres re-cross in the cerebellar region. From here the third-order neurone arises and goes to the cerebellar cortex. **Function**—*It carries unconscious kinaesthetic sensation.*

5. **Spino-olivary tract** (FIG. 5.119). This tract is originated from the cells of the dorsal horn of gray matter of all levels of the spinal cord,

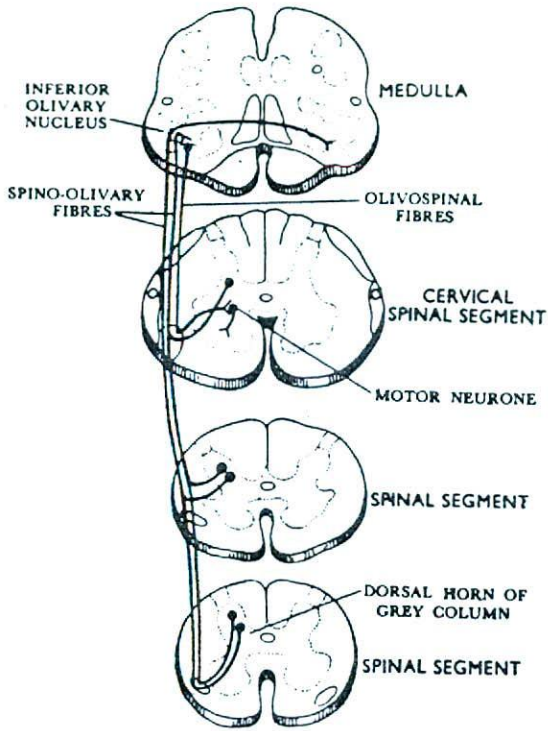


FIG 5.119 Diagrammatic representation of spino-olivary tract and of olivospinal tract.

runs in parallel with the *olivospinal tract* and ends mostly in the inferior olivary nucleus of the opposite side. More than half of the fibres cross in the medulla oblongata. **Function**—The spino-olivary tract transmits proprioceptive impulses to the cerebellum *via* the inferior olivary nucleus. It is claimed that this tract constitutes a component of the spinocerebellar tract.

6. **Spinoreticular tract** (FIG. 5.120). Cell stations of these fibres are lying in the posterior horn cells at all levels of the spinal cord. These fibres ascend in the anterolateral funiculus and terminate chiefly in the *nucleus reticularis gigantocellularis* and partly in the *lateral reticular nucleus* in the medulla. In the pons, certain fibres terminate in the *nucleus reticularis*

pontis caudalis. A small number of fibres also terminate in the mesencephalic reticular formation. This tract also gives collaterals to the thalamus and hypothalamus. **Function**—This tract plays an important role in the maintenance of consciousness and awareness.

7. **Spinovestibular tract.** This tract is originated from the spinal fibres projecting largely upon the dorsal part of the *lateral vestibular nucleus*. It ascends in the ipsilateral column of the spinal cord from the level as far as lumbar segments. **Function**—This tract is concerned with postural reflexes.

8. **Spinopontine tract.** These fibres are largely collateral fibres of spinocortical fibres (*vide* below) and ascend along with the spinocortical fibres and lastly terminate in the pontine nucleus. **Function**—It is suggested that these fibres are concerned with the certain exteroceptive impulses to the cerebellum.

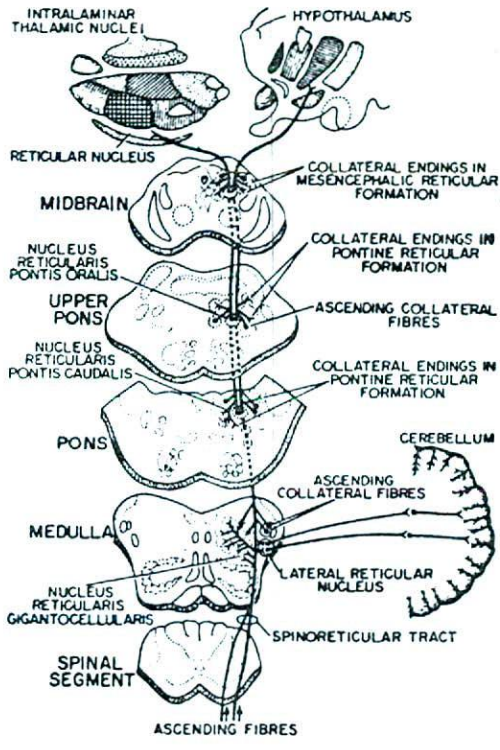


FIG 5.120 Diagrammatic representation of spinoreticular and collateral reticular projections at different brain stem levels.

9. **Spinocortical tract.** The presence of these fibres has been described recently. This tract ascends in parallel with the corticospinal tract. These fibres arise from all parts of the spinal cord and largely from the cervical region. The **functions** of these fibres are not clear.

III. AFFERENT (SENSORY) TRACTS IN THE ANTERIOR COLUMN

1. **Ventral (Anterior) spinothalamic tract** (FIG. 5.121).

(*a*) **Origin, distribution and termination**—This tract originates from the large cells of the *nucleus centrodorsalis* of the posterior horn and second-order neurone starts from here. Axons of the second-order neurone ascend in the posterior column for two or three spinal segments and then cross obliquely in the anterior white commissure and thus ascend in the anterior or anterolateral column of the opposite side as ventral (anterior) spinothalamic tract. Most of the fibres are *crossed* and a small number of fibres are *uncrossed* and may ascend homolaterally as anterior spinothala-

mic tract. While ascending upward the ventral (anterior) spinothalamic tract runs in parallel with the lateral spinothalamic tract in the spinal lemniscus.

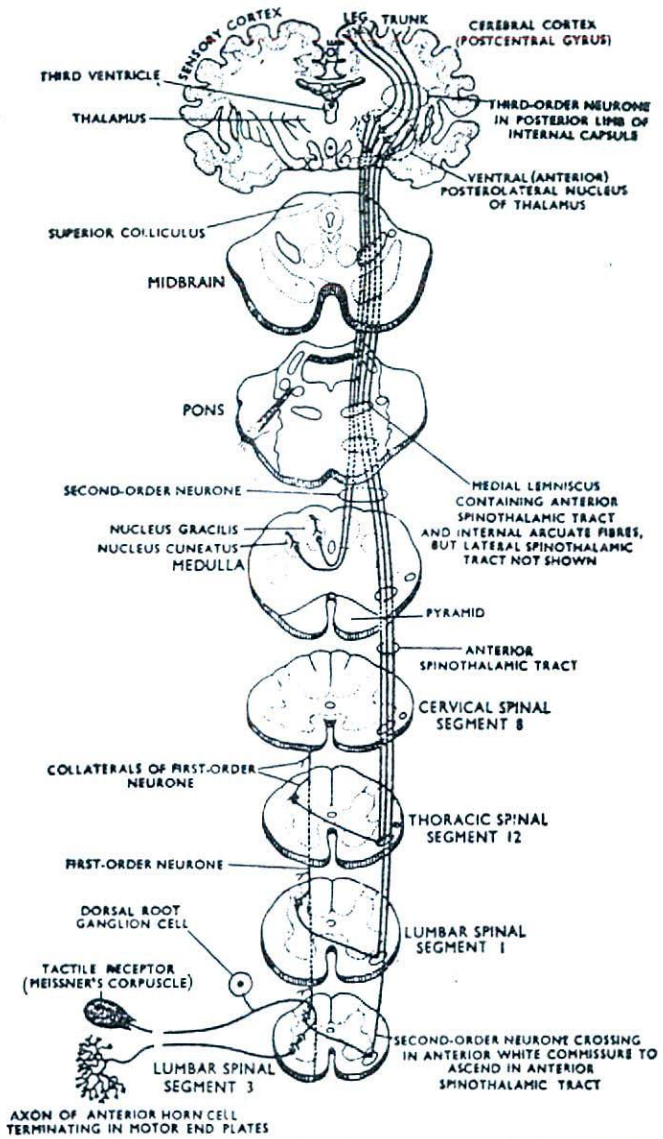


FIG 5.121. Diagrammatic representation of ventral (anterior) spinothalamic tract.

As the tracts ascend towards the brain stem, a certain number of fibres are reduced gradually. The tracts give certain collaterals to the dorsolateral part of the brain stem reticular formation and also to the lateral

Epicritic - fine sensations.
Protopathic - less sensibility.

reticular formation. At the upper border of the pons and midbrain, this tract along with dorsal spinothalamic tract (lateral spinothalamic tract) and internal arcuate fibres runs in the medial lemniscus and terminates in the ventral posterolateral nucleus of the thalamus. The thalamus is known as subcortical centre for the spinothalamic tract. Here second relay starts and axons of the third-order neurone in posterior limb of the internal capsule terminate in the postcentral gyrus.

(*b*) **Function**—This tract is for fine touch and tactile localisation.

Summary of the pathways of various sensations

Path of touch. Tactile corpuscles → thicker medullated fibres in the sensory nerves → posterior root → spinal cord. Here, the touch fibres become divided into two parts: (*a*) Epicritic part passes through the tracts of Goll and of Burdach. (*b*) Protopathic part passes through the ventral (anterior) spinothalamic tract.

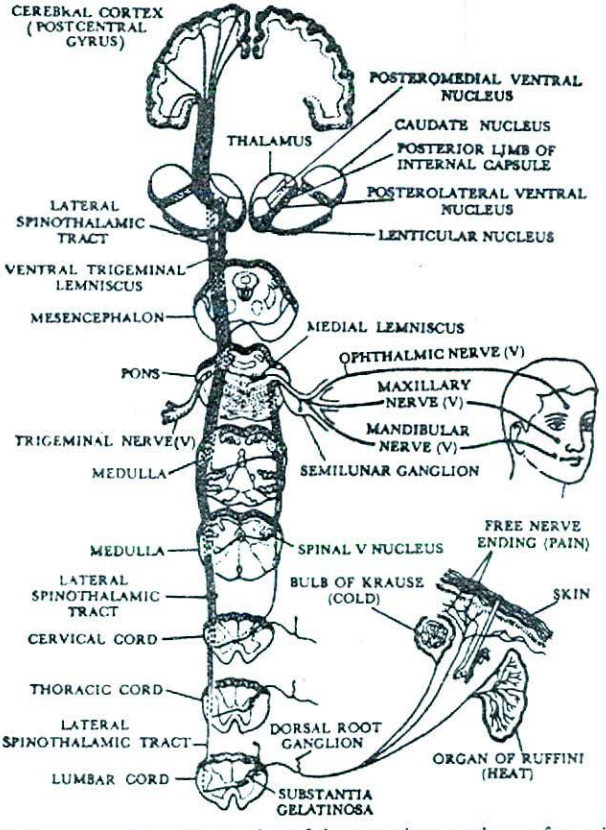


FIG 5.122. Diagrammatic representation of the conscious pathway for pain and temperature including the types of receptors.

Path of pain and temperature. Nerve endings for pain are the *free nerve terminals*. For cold *end organs of Krause;* for heat, *organs of Ruffini*

and the *Golgi-Mazzoni* bodies. Pain is carried by fine non-medullated fibres, whereas thermal senses by medium-sized medullated fibres. All pass through the sensory nerves to the posterior root and enter the spinal cord. Fibres carrying pain and temperature sensations constitute Lissauer's tract and end in the posterior horn cells. From the posterior horn cells the second-order neurone arises and forms the dorsal spinothalamic tract (lateral spinothalamic tract) (*vide* pp. 5-112, 113) The crude part (protopathic) of temperature sensation and pain end in the thalamus, whereas the fine part (epicritic) of temperature sensation is relayed to the sensory cortex (Fig. 5.122).

Path of kinaesthetic impulses (also Vibration Sense). *End organs*—muscle spindles, Golgi bodies, Pacinian corpuscles, etc. (Fig. 5.123) Impulses

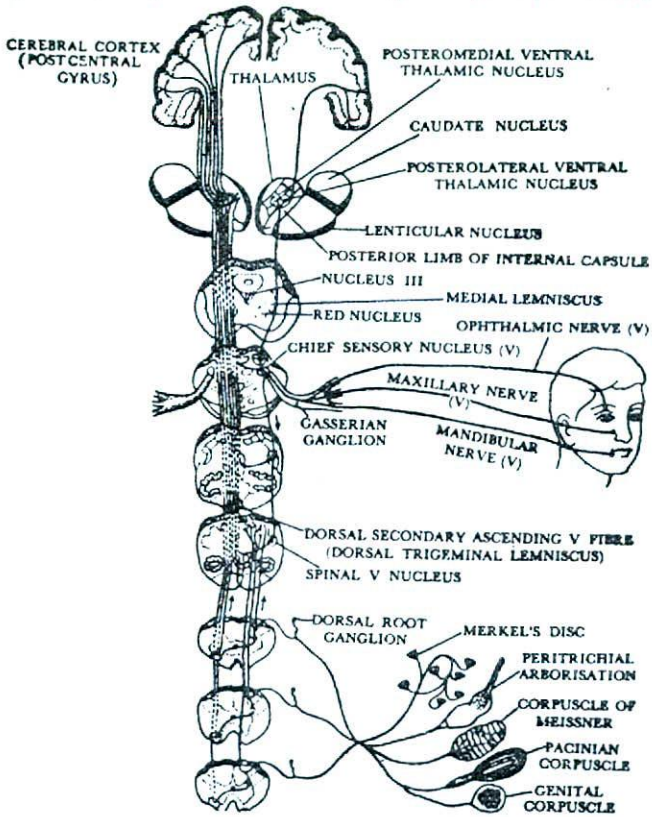


Fig 5.123. It shows the conscious pathway for light (crude) touch.

pass along the sensory nerve → posterior root → spinal cord. Here, two divisions: (*a*) Conscious kinaesthetic impulses pass through the tracts of Goll and of Burdach. (*b*) Unconscious kinaesthetic impulses pass through Flechsig's and Gower's tracts.

Path of non-sensory afferent impulses. These afferent impulses do not rise to the level of consciousness. Hence, the tracts carrying them will end somewhere below the thalamus. They are mentioned below.

1. **Spinocerebellar tracts**—Flechsig's and Gower's. They carry non-sensory kinaesthetic impulses to cerebellum. Very important for tone, posture and equilibrium.
2. Those **fibres of Goll and of Burdach** which are relayed to the cerebellum through the external arcuate fibres, probably carry unconscious kinaesthetic impulses.
3. **Spinotectal tract** ending in the superior colliculus and responsible for spinovisual reflexes.
4. **Small intersegmental tracts** (Comma tract of Schultze, Septomarginal tract, etc.)—necessary for co-ordination and reflex.
5. **Spino-olivary fibres.** From spinal cord to inferior olive, probably for reflex.

HOW POSTERIOR SPINAL ROOT ENDS

The posterior root is composed of: (*a*) autonomic fibres, (*b*) somatic fibres. The autonomic fibres all end in the lateral horn cells. The somatic fibres terminate as follows:

1. Fibres carrying pain, temperature and crude touch end round the posterior horn cells on the same side. From here, the second-order neurone arises and passes out as the spinothalamic tract. Before ending in the posterior horn the pain and temperature fibres constitute the so-called tract of Lissauer.
2. Fibres carrying unconscious kinaesthetic impulses end in Clarke's column of the same side. From here the second-order neurone arises and carries the impulses to the cerebellum through the two spinocerebellar tracts.
3. Some fibres pass directly to the anterior horn cells and establish various reflex arcs, viz., knee jerk, etc.
4. Fibres carrying conscious kinaesthetic impulses and fine touch enter the posterior white column of the same side, constitute the tracts of Goll and of Burdach and end in the nucleus gracilis and the nucleus cuneatus respectively in the medulla. Collaterals of these tracts also end: (*a*) round the posterior horn cells, (*b*) form short intersegmental tracts, such as comma tract of Schultze, and (*c*) may form reflex arcs.

DESCENDING TRACTS

Motor Tracts or Efferent Tracts

I. Pyramidal Tracts:
- (*a*) **Crossed pyramidal tract** (Large lateral corticospinal tract).
- (*b*) **Direct pyramidal tract** (Uncrossed anterior corticospinal tract).
- (*c*) **Uncrossed small lateral pyramidal (corticospinal) tract.**

II. Corticobulbar Tract.

III. Extrapyramidal Tracts:
- (*a*) **Rubrospinal tract.**
- (*b*) **Tectospinal tract and Tectobulbar tract.**
- (*c*) **Reticulospinal tract.**
- (*d*) **Vestibulospinal tracts.**
- (*e*) **Olivospinal tract (Bulbospinal tract).**
- (*f*) **Descending medial longitudinal fasciculus.**

I. PYRAMIDAL OR CORTICOSPINAL TRACTS

(Corticospinal tracts – Figs. 5.124 & 5.130)

(a) Composition – This is the longest tract starting from the motor cortex and reaching up to the last segment of the cord. These tracts are constituted by the fibres originating from the cells of the cortex, pass

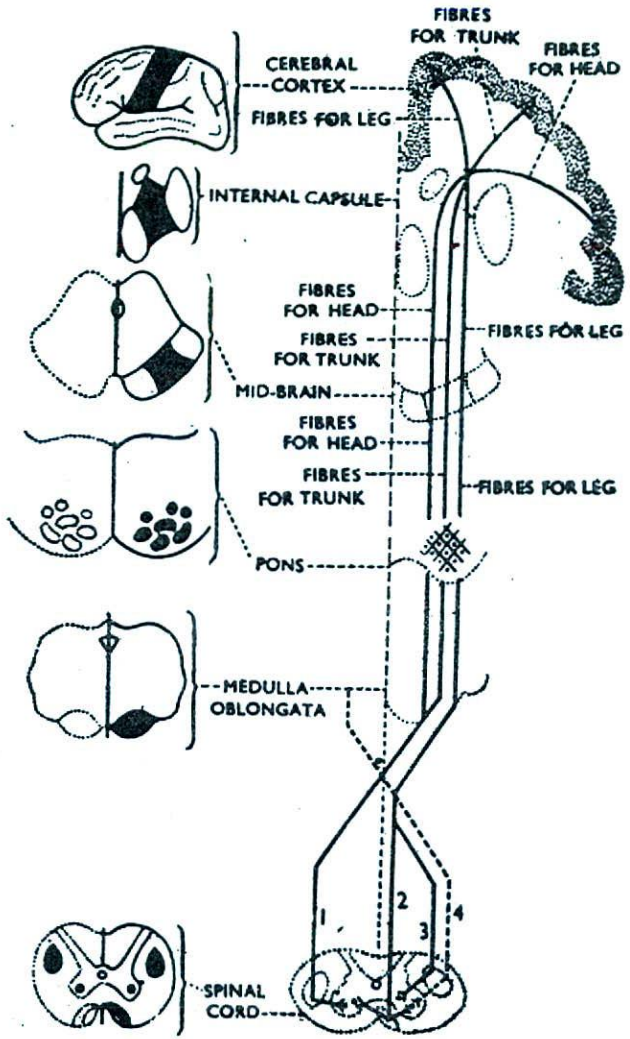


FIG. 5.124. Composite diagrammatic representation of pyramidal tracts (simplified). 1 = Crossed pyramidal tract. 2 = Direct pyramidal tract. 3 = Uncrossed small pyramidal tract. 4 = Crossed pyramidal tract from the other side.

through medullary pyramid and enter the spinal cord. Due to incomplete decussation at the junctions of the medulla and spinal cord, there originate

the *three* tracts: (*a*) the *crossed pyramidal tract* (*large lateral corticospinal tract*), (*b*) the *direct pyramidal tract* (*uncrossed anterior corticospinal tract*), and (*c*) a *uncrossed small lateral pyramidal tract* (FIG. 909). It is present only in the higher animals and man where cerebrum has developed. It is composed of about one million nerve fibres of which 60% are myelinated and 40% unmyelinated. Of the myelinated fibres over 80% are of 1–3 μm size, only 4% are over 11 μm and 2% are 12–20 μm. Since majority of fibres are of small diameter, the tract must be a slowly conducting pathway.

(*b*) **Origin**—It is generally believed that the fibres arise from the giant (large) pyramidal cells (Betz cells) of area 4 in the precentral gyrus. But two observations are against this conclusion: (*a*) There are only about 35,000 Betz cells, which can account for only 6% of the fibres of this tract. (*b*) After ablation of area 4, only 25% of the fibres degenerate and 75% survive. The origin of this tract is not only from areas 4 and 6 but also from frontal and parietal lobes as after ablation of areas 4 and 6 all the pyramidal fibres do not degenerate. Ablation of areas 3, 1, 2, 5 and 7 leads to degeneration of the remaining fibres.

Course and termination of pyramidal tracts

The *course of pyramidal tracts* is described below region by region:

In the cortex—As mentioned above, fibres arise from the whole of the precentral gyrus. The fibres are arranged upside down like the motor centres (*vide* motor area). Those for the toes are at the top, those for the trunk in the middle and those for the head, below. The fibres descend in the same plane (coronal) as occupied by the central sulcus.

Corona radiata—The cerebral hemisphere is connected with the brain stem and spinal cord by projection fibres. These projecting fibres of the cerebral cortex converge towards the brain stem as a radiating mass

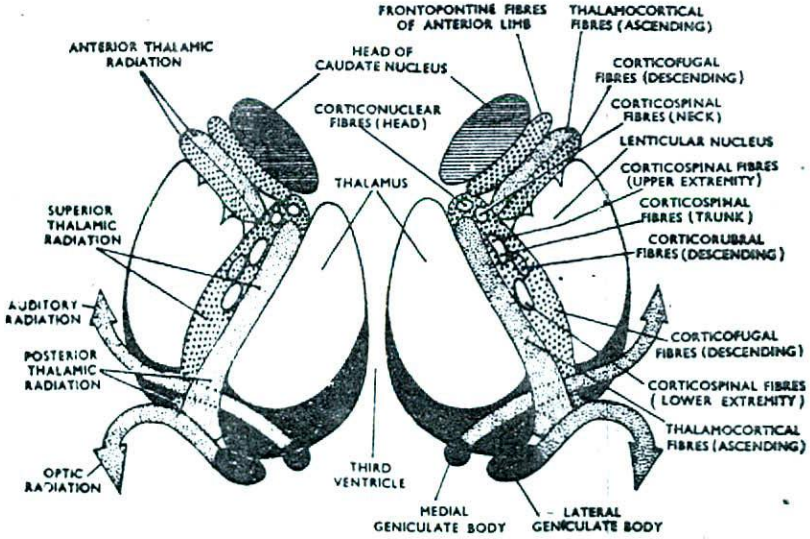


FIG. 5.125. Diagrammatic representation of different components of the internal capsule showing thalamic, auditory and optic radiations.

of fibres which is known as *corona radiata*. The fibres then converge and pass through the internal capsule.

In the internal capsule—The cortical fibres then pass through the internal capsule, occupying the *genu* (bent of the internal capsule) and the *anterior two-thirds of the posterior limb*. The cortical descending fibres which pass through the genu of the internal capsule constitute the corticobulbar or corticonuclear tract. The cortical descending fibres which pass through the anterior *two-thirds* of the internal capsule are known as **corticospinal or pyramidal tracts.** Here the plane of the fibres rotates through one right angle and the relative position of the fibres changes. The 'head' (upper extremity) fibres now occupy the most anterior part, the 'leg' (lower extremity) fibres, the most posterior part and the 'trunk' fibres remain in the middle. Here, the tract gives fibres to the following: **Corticobulbar (corticonuclear) fibres** pass down the midbrain and end round the motor nuclei of V, VII, IX, X, XI, XII cranial nerves of the same and opposite side through the intercalated neurones of the reticular formation. Just behind the pyramidal tract remain the thalamic radiation, optic radiation, auditory radiation and temporopontine fibres (Fig 5.125).Following fibres pass through the anterior limb of the internal capsule: (*a*) *thalamofrontal*, (*b*) *frontothalamic*, (*c*) *frontopontine*, and (*d*) *corticostriate*. [For details *vide Internal capsule.*]

In the midbrain—The corticospinal and corticobulbar fibres occupy the middle *three-fifths* of the crus cerebri. The anterior *one-fifth* is occupied by the *frontopontine* and the posterior *one-fifth* by the *temporopontine fibres*

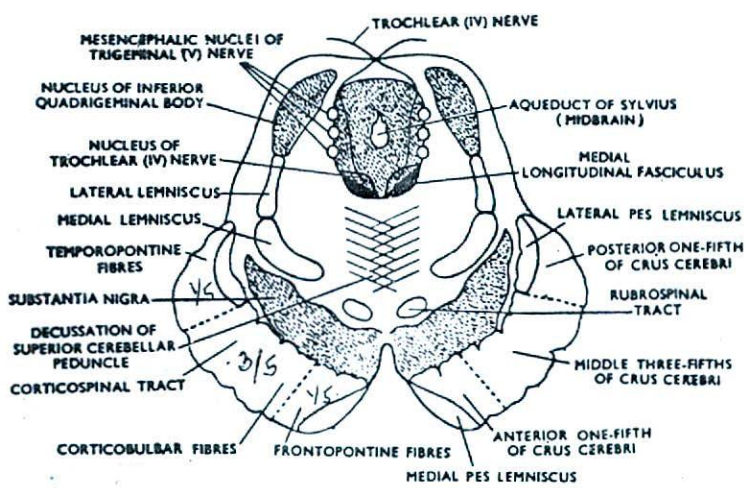


Fig. 5.126.-Diagrammatic sectional representation of the midbrain showing the space of reticular formation surrounded by medial lemnisci at the level of inferior quadrigeminal body.

(Fig.5.126).Here, the plane of the pyramidal tract turns through another right angle and the fibres undergo a second rearrangement. The 'head' fibres remain medially, 'leg' fibres laterally and the 'trunk' fibres in the middle.

In the pons—The pyramidal fibres occupy the most ventral aspect of pons in front of the trapezium. While passing through the nuclei pontis and the crossing fibres of the middle cerebellar peduncle, the tract is broken up into scattered bundles and the previous arrangement of fibres is probably lost (FIG. 5.127).

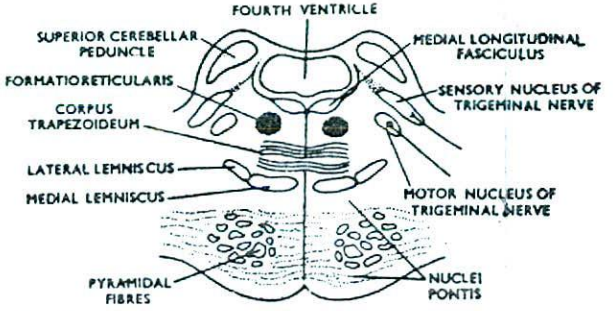


FIG. 5.127. Diagrammatic sectional representation through the upper pons.

In the medulla—While coming out of pons the scattered fibres are reunited and enter the medulla as a thick bundle. It occupies the most anterior part of the medulla producing a distinct bulge—the *pyramid*. In the lower part of medulla the majority of fibres cross, while the rest pass down on the same side (FIGS 5.128 & 5.129).

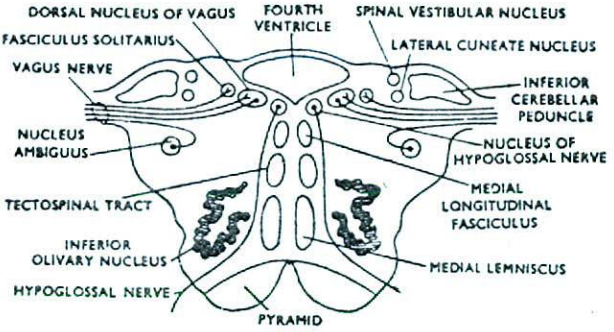


FIG. 5.128. Diagrammatic sectional representation through the upper medulla showing the space of the reticular formation between the pyramids and the central gray matter on the floor of the fourth ventricle.

In the spinal cord—Pyramidal fibres end in the spinal cord mostly at the interneurones in the following manner (FIGS 5.124 & 5.131).

(*a*) **Crossed pyramidal tract** (Large lateral corticospinal tract). The fibres which cross in the medulla constitute this tract. While crossing, the fibres bend a little backwards, enter the lateral white column and remain just behind the rubrospinal tract. It extends throughout the whole cord and at each segment some fibres leave the tract, turn inwards and end round the anterior horn cells either directly or through interneurones.

(*b*) **Direct pyramidal tract** (Uncrossed anterior corticospinal tract). It is made up of those fibres which do not cross in the medulla. The

tract enters the anterior white column near the median fissure (cleft). Some of its fibres cross to the opposite side through the anterior white

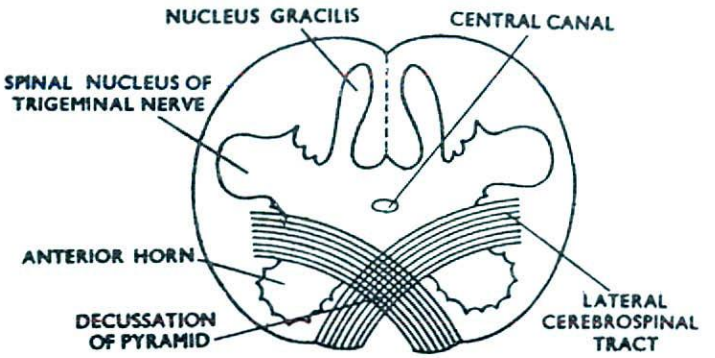


FIG. 5.129. Diagrammatic representation of the dorsal aspect of the medulla at the level of efferent decussation of pyramids (cerebrospinal fibres).

commissure and end round the anterior horn cells of the opposite side (FIG. 5.124). The rest of the fibres remain on the same side and end round the anterior horn cells of the same side. It is generally held that this tract does not reach beyond the thoracic region, but others have traced it up to the sacral region. One should note that although the fibres do not cross in the medulla, some of them cross in the spinal cord near their termination.

(*c*) **Uncrossed small lateral pyramidal tract.** Lately Fulton and Sheehan have described the presence of another tract of a few uncrossed lateral pyramidal fibres (**anterolateral pyramidal tract of Barnes**) descending through the lateral white column and terminating on the same side. The presence of these and the second group of fibres of the direct pyramidal tract indicates that certain muscles in the body must have bilateral control from both cerebral hemispheres. In pyramidal lesions of one side they will escape paralysis. The respiratory muscles are the typical examples.

Regarding the **termination of the pyramidal fibres** there are two views: (1) The general belief is that they end directly round the anterior horn cells. (2) **Schäfer** holds that they first end somewhere near the posterior horn and are then relayed to the anterior horn cells by an internuncial neurone.

Of all the pyramidal fibres 55% *end in the cervical*, 20% *in the thoracic and* 25% *in the lumbosacral region.*

Pyramidal cells and their axons are known as **upper motoneurone** and spinal cord motoneurones with their axons are known as **lower motoneurone.**

The *paralysis of the upper motoneurone* shows loss of the volitional movement, loss of superficial reflexes, increased deep reflexes, spasticity and the sign of Babinski. The *paralysis of the lower motoneurone* shows loss of all voluntary and reflex movements. Loss of muscle tone along with muscular dystrophy is observed.

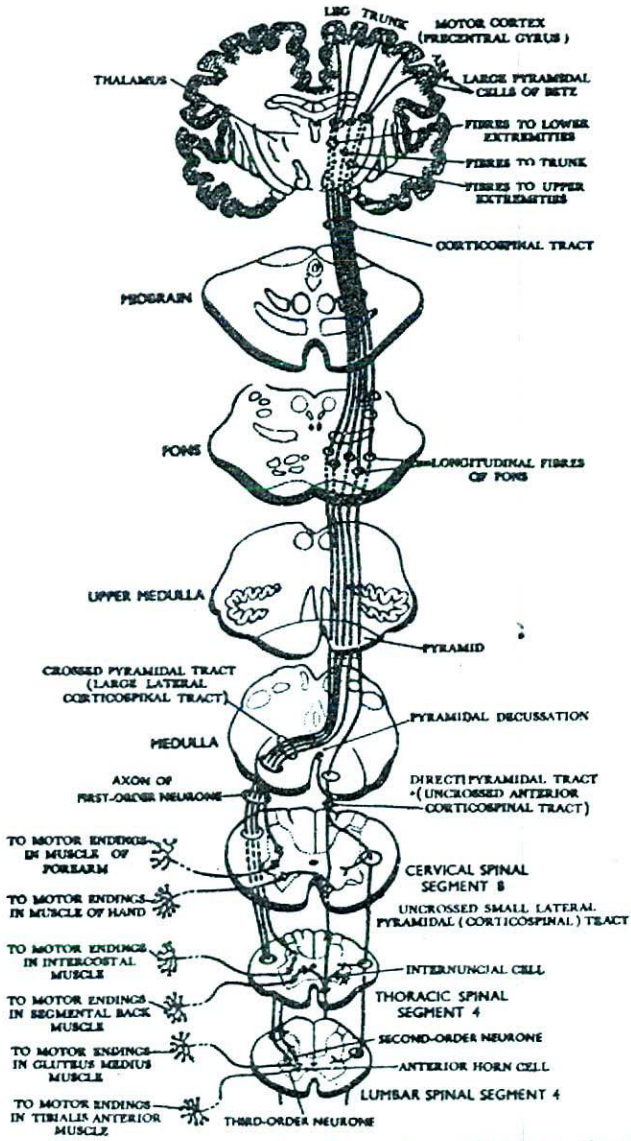


FIG 5.130. Diagrammatic representation of crossed pyramidal tract (*large lateral corticospinal tract*), direct pyramidal tract (*uncrossed anterior corticospinal tract*) uncrossed small lateral pyramidal (corticospinal) tract, but *crossed pyramidal tract of the opposite side is not shown.*

Functions of the pyramidal tracts

1. The pyramidal tracts convey motor impulses to the spinal cord for controlling the voluntary movement especially the movement of fingers and hand subserving skill work.

Ankle clonus - A series of rapid and contraction of calf mus when foot is dorsiflexed by pressure upon the sole.

2. They also form a part of the pathways for superficial reflexes like the cremasteric, abdominal and plantar reflexes.

Effects of section of the pyramidal tracts

After the section of pyramidal tracts in Rhesus monkeys at the lower level of the medulla oblongata or in the lateral column of the spinal cord following effects are observed:

(*a*) **Voluntary movement.** Disturbance of voluntary movements specially of the opposite arm and leg. The discrete movements of the fingers, walking, grasping, scratching, etc., cannot be properly performed.

(*b*) **Muscle tone.** Diminution of muscle tone specially of the limbs is encountered. Increased muscle tone and exaggerated reflexes occur after section of both pyramidal and extrapyramidal tracts.

(*c*) **Reflexes.** Abolition of superficial reflexes namely abdominal, cremasteric, etc., and slowing of the deep reflexes.

In human beings the acute lesion of pyramidal tracts involving also the extrapyramidal fibres (which remain intermingled) at the level of the internal capsule gives rise to paralysis of the opposite side of the body. This is called **hemiplegia** (Fig.5.141).The muscles remain flaccid and reflexes cannot be elicited. Voluntary movements of the upper and lower limbs cannot be performed. This is the stage of *shock*. The **shock stage** usually passes away and the tone of the muscles of the paralysed limbs increases and the muscles become spastic. Superficial reflexes, viz., abdominal, cremasteric, etc., are lost on the affected side and plantar reflexes become extensor, i.e., *Babinski* response (Fig.5.140). The deep reflexes, viz., knee jerk, ankle jerk, etc., are exaggerated. Ankle clonus may be present.

II. CORTICOBULBAR (CORTICONUCLEAR) TRACTS (Fig.5.131)

These tracts originated from the cells in the inferior portion of the precentral gyrus and the caudal part of the inferior frontal gyri pass through genu of the internal capsule (Fig 5.125)on page 5-124) and are largely distributed bilaterally to the intercalated neurones in the reticular formation. These intercalated neurones then in turn project abundantly into the motor cranial nerve nuclei. [*Vide* page 1232.] Golgi studies of the intrinsic organisation of the reticular formation have indicated the presence of such connection between the intercalated neurones and the cranial nerve nuclei. Kypers (1958) has indicated that in man some **corticofugal fibres** pass directly to the motor trigeminal, facial, hypoglossal and also supraspinal nuclei.

Functions—The corticobulbar tracts are essentially meant for volitional control of the muscles of the larynx, pharynx, palate, upper and lower face, jaw, eye, etc.

Pseudobulbar palsy is a condition, resulting paralysis or weakness of the muscles which control swallowing, talking and movements of the tongue and lips due to bilateral lesions of the corticobulbar tracts.

III. EXTRAPYRAMIDAL TRACTS

Extrapyramidal tracts are those motor pathways which may act as the alternative route for volitional impulses and which form the platform on which the pyramidal system works skilfully.

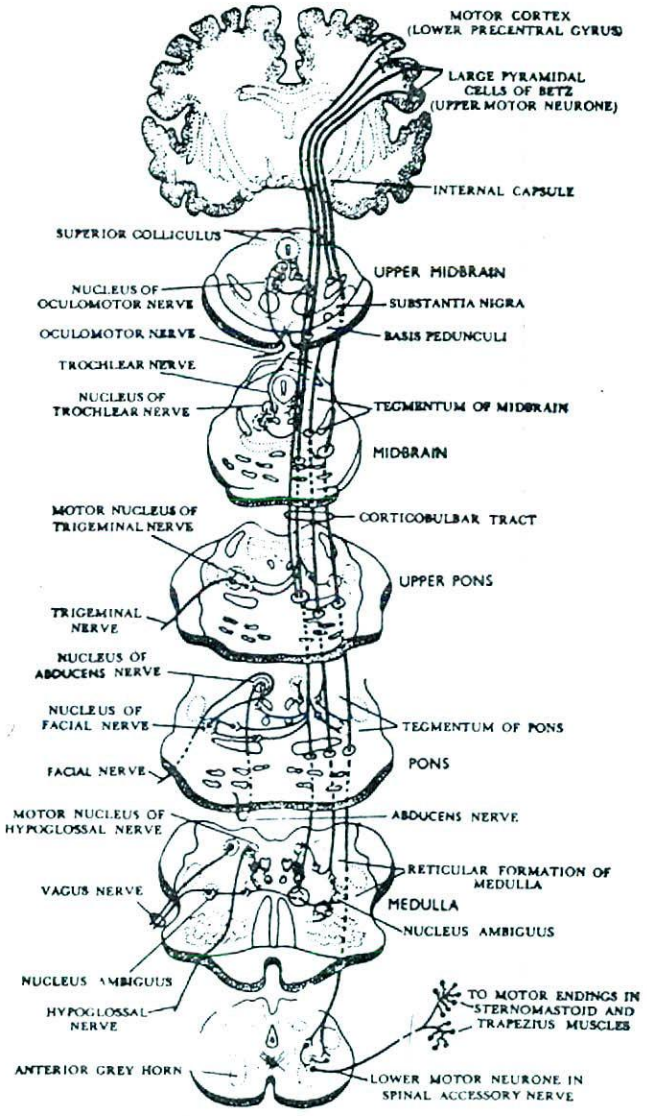


FIG 5.131. Diagrammatic representation of corticobulbar tract showing the connection with the different motor nuclei of cranial nerves through intercalated neurones in the reticular formation.

With this conception of the extrapyramidal system, it is expected that all tracts belonging to this system must be connected, directly or indirectly, with the corpus striatum or cerebrum or both. It is integrated at various levels all the ways from the cerebral cortex to the spinal cord. When the neural pathway is interrupted, the integrated activities below

the section are disturbed or released from the control of higher brain centres. The cortical regions controlling these tracts are the areas 8 and 6 specially the latter (extrapyramidal area). Since these areas exchange fibres with area 4 (pyramidal area) they seem to work in perfect co-ordination. The following tracts are believed to satisfy this condition and, therefore, belong to this system (Fig. 5.132).

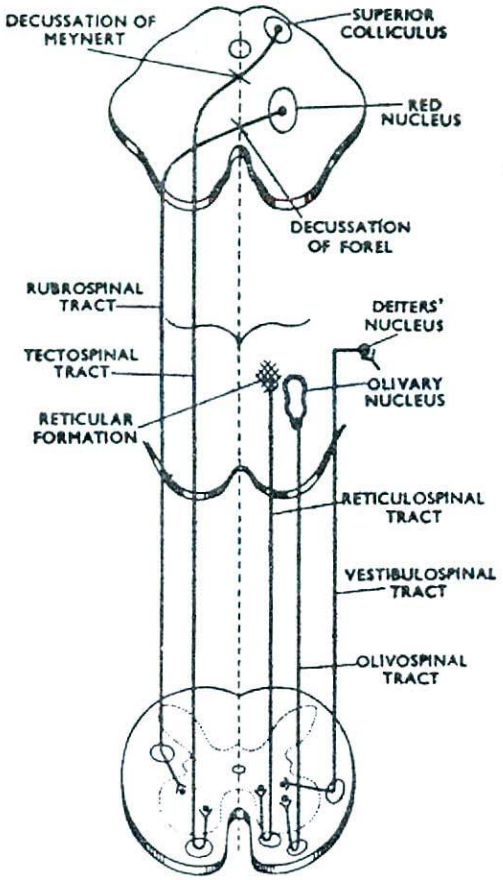


Fig. 5.132. Composite diagrammatic representation of extrapyramidal tracts (simplified).

1. **Rubrospinal tract** (Monakow's bundle, Prepyramidal tract). It is a relatively small bundle of fibres arising from the *nucleus magnocellularis* of the red nucleus crosses immediately to the opposite side (**Forel's decussation**) ventral to the Sylvian aqueduct. While descending down through the brain stem, some fibres of this tract end in the cerebellum and a moderate number also project to the lateral reticular nuclei of the medulla. This tract is not extended below the thoracic segment of the

spinal cord in man. Cervical cord receives maximum number of fibres. It lies dorsally in pons, ventrally in medulla, enters the lateral white column of the spinal cord in front of the crossed pyramidal tract and ends largely upon internuncial neurones in the intermediate zone at the base of the anterior horn cells (FIG. 5.133).

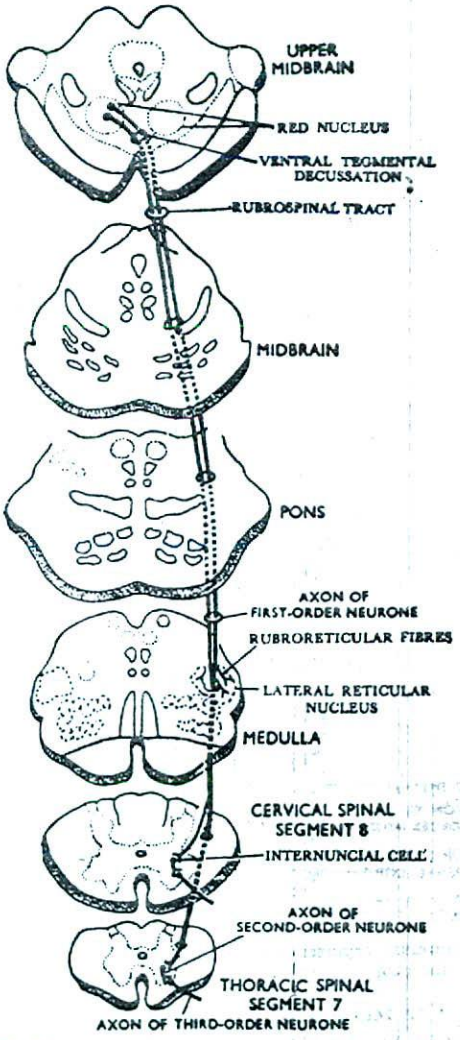


FIG. 5.133. Diagrammatic representation of rubrospinal tract and rubroreticular fibres.

Functions. The *red nucleus* and *rubrospinal tracts* have got facilitatory influence over flexor muscle tone.

2. **Tectospinal tract and Tectobulbar tract.** These two tracts

are originated from the deeper layers of the superior colliculus and cross at once (**decussation of Meynert**) ventral to central aqueduct. At the medullary level the fibres of the tectospinal tract descend in the medial longitudinal fasciculus as far as lower cervical segments and terminate upon the internuncial and anterior horn cells (Fig. 5.134).

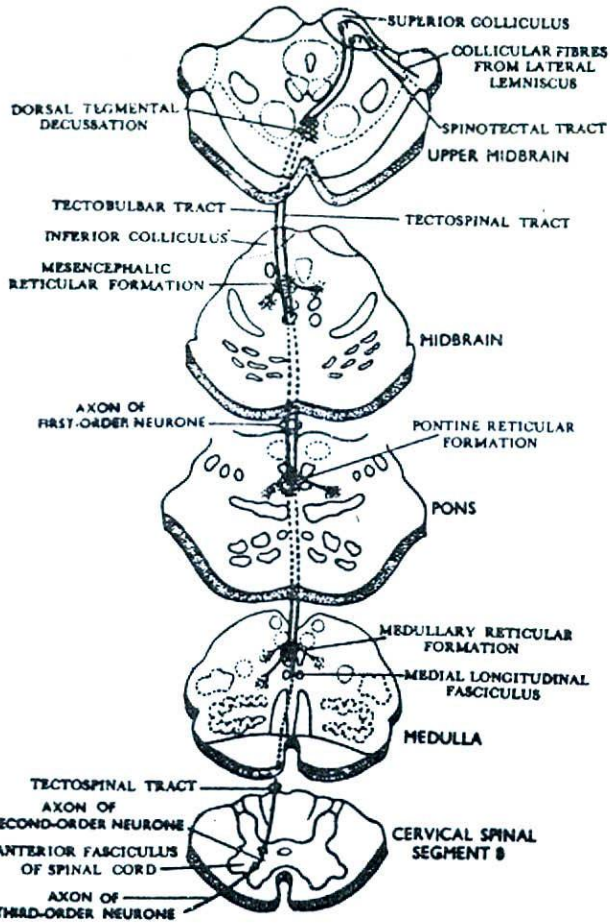


Fig. 5.134. Diagrammatic representation of tectobulbar tract and tectospinal tract showing separate locations of reticular formation.

Function. The tectospinal tract conveys impulses subserving reflex postural movements in response to visual and auditory stimuli.

The tectobulbar tract is distributed to the mesencephalic reticular formation bilaterally and to the contralateral pontine and medullary reticular formation.

3. **Reticulospinal tracts.** These tracts are originated from the neurones of the pontine and medullary reticular formation and descend

in the anterior and antero-lateral portions of the spinal cord. Fibres from the pontine reticular formation, mainly crossed, are originated from the nuclei of reticularis pontis oralis and of reticularis pontis caudalis, and descend chiefly in the medial part of the anterior funiculus of the spinal cord and for this reason these fibres are also known as *medial reticulospinal fibres* (FIG. 5.135).

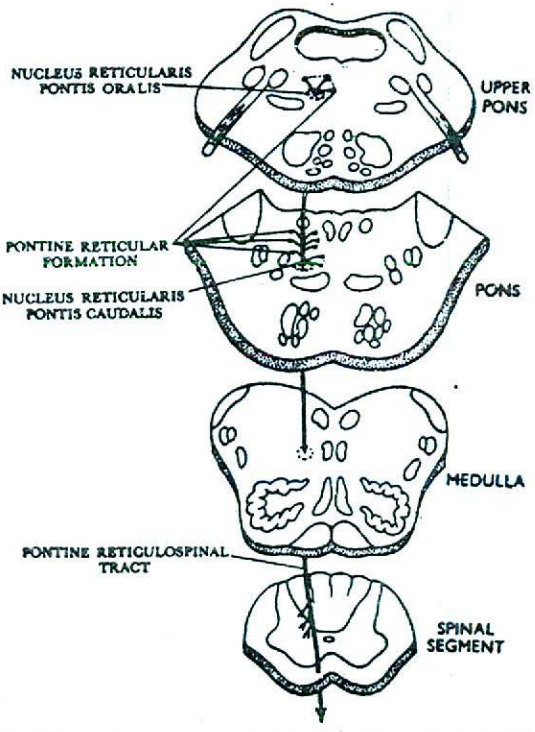


FIG. 5.135. Diagrammatic representation of pontine reticulospinal tract (medial reticulospinal fibres).

Medullary reticular fibres, mostly uncrossed, are originated from the nucleus reticularis gigantocellularis and descend primarily in the anterior part of the lateral funiculus. Most of the axons of these tracts terminate probably upon the internuncial neurones of the anterior horn of the spinal cord and hence these fibres are also known as *lateral reticulospinal fibres* (FIG. 5.136).

Function. (*i*) Stimulation of the brain stem reticular formation can facilitate or inhibit voluntary movement. (*ii*) Alter muscle tone. (*iii*) Respiration is modified. (*iv*) Blood pressure is altered. (*v*) Central transmission of sensory impulses is altered.

It has been observed that *nucleus reticularis gigantocellularis* (with the exception of its most rostral part) constituting the medullary reticular fibres is related to inhibition. Stimulation of the nucleus reticularis gigantocellularis produces inhibition of exaggerated extensor muscle tone in dece-

rebrate animals. On the other hand, the nucleus of medullary reticular fibres has got exaggerated effect on the extensor muscle tone in the decerebrate animals as the suppressor area (4S) of the cerebral cortex fails to inhibit the motor activities of this nucleus. Recent studies have claimed

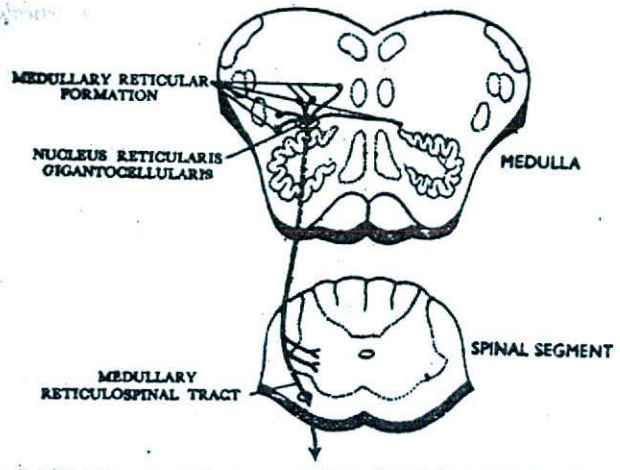


FIG. 5.136. Diagrammatic representation of medullary reticulospinal tract (lateral reticulospinal fibres).

that medullary reticulospinal tract influences the spinal cord -motoneurone whose axons terminate in the motor end-plate of the intrafusal fibres of the muscle spindle (*vide* pp 5-168. 5-169). Normally the area 4S (suppressor area) inhibits the motor activities of the nucleus of the medullary reticulospinal tract. Other effects of stimulation of these neclei produce deep inspiration and depression of blood pressure.

The *nucleus reticularis pontis caudalis* and *nucleus reticularis pontis oralis* constituting the pontine reticulospinal tract and also the *dorsal nucleus of the reticularis gigantocellularis* of the medulla are concerned with facilitation. The stimulation of these nuclei facilitates voluntary movement, expiration and also increases pressor (vasomotor) effects.

4. **Vestibulospinal tracts.** The *lateral vestibulospinal tract* is originated from the lateral vestibular nucleus (Deiters' nucleus) of the medulla of both sides. This nucleus also receives fibres from the vestibular division of the eighth cranial nerve and also from the cerebellum. This tract descends the entire length of the spinal cord and ends in the medial part of the anterior horn cells of the gray matter (Fig. 5.137). This tract does not descend in the medial longitudinal fasciculus.

The *medial vestibulospinal tract* — A small number of fibres, crossed and uncrossed, originated from the medial and probably from the inferior vestibular nucleus also, descend in the medial longitudinal fasiculus up to upper thoracic spinal segment and enter the sulcomarginal area of the anterior funiculus (Fig. 5.138). The superior olivary nucleus does not give any fibres to the spinal cord. It is claimed that this descending tract may project some fibres to the lower brain stem reticular formation. Besides these, this tract may give fibres to the visceral motor nuclei, such as

dorsal motor nucleus of vagus, autonomic cell groups and secretory nuclei.

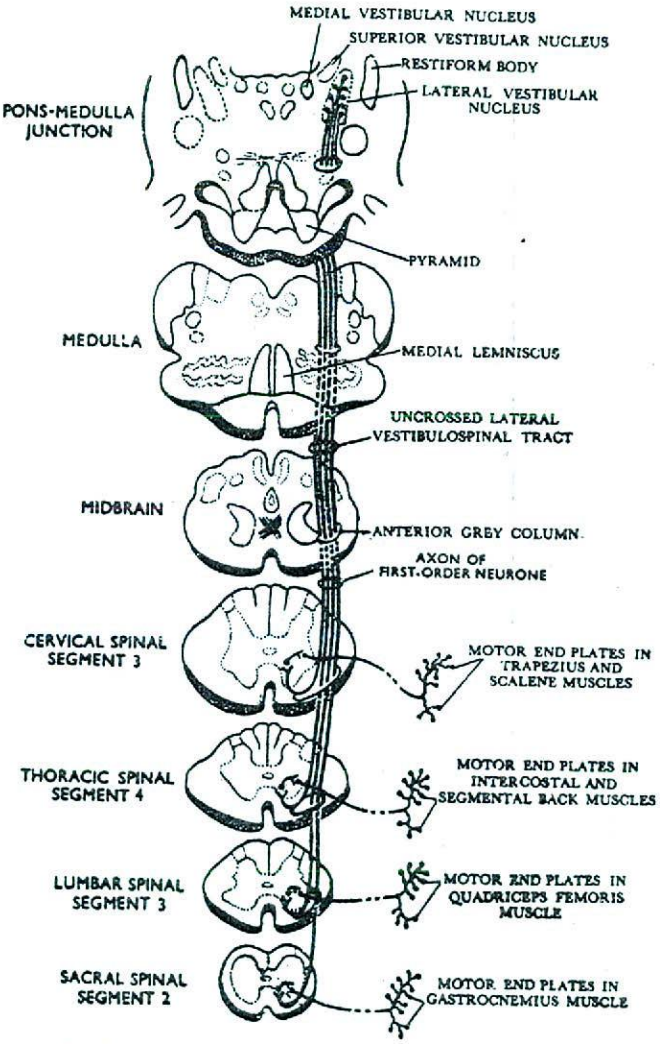


FIG. 5.137. Diagrammatic representation of uncrossed (direct) lateral vestibulospinal tract.

Function. Lateral vestibular tract exerts facilitatory influences on reflex spinal activities and also spinal mechanism underlying the muscle tone. Electrical stimulation of the lateral vestibular nucleus produces increased extensor muscle tone of the fore limbs or hind limbs. Cerebellar influence on muscle tone and posture is exerted through the mediation of the vestibulospinal tract.

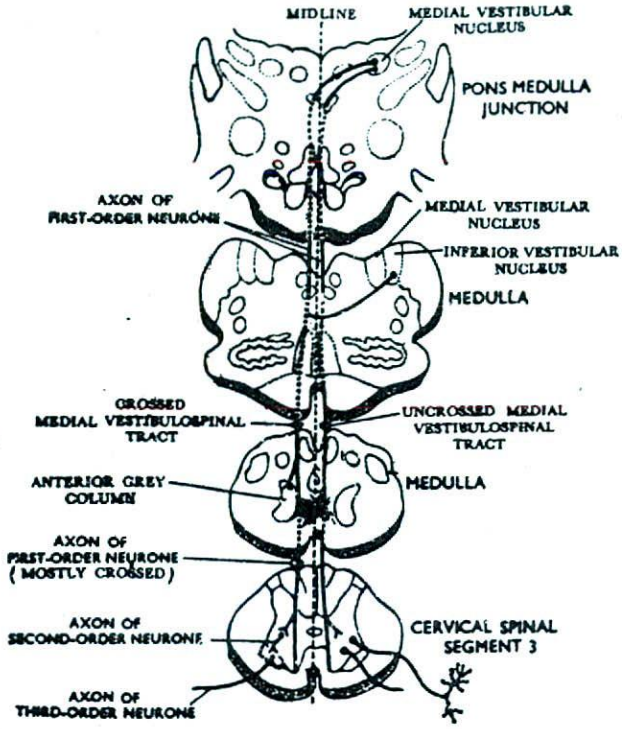


FIG. 5.138. Diagrammatic representation of crossed (indirect) and uncrossed (direct) medial vestibulospinal tracts.

Medial vestibulospinal tract is concerned with different reflex phenomena, such as nausea, vomiting, vasomotor reactions, palpitation, perspiration, facial pallor, etc. It also appears to be concerned with conjugate horizontal eye movements and integration of eye and neck movements.

5. **Olivospinal tract** (Bulbospinal tract or Tract of Helweg). It possibly arises from the inferior olivary nucleus, enters the anterior part of the lateral white column and ends round the anterior horn cells. The existence of this tract is doubtful. It is found in the cervical region only (FIG. 5.119 in page 5-123).

Function. The function of this tract is unknown. Since cortex communicates with the thalamus and the latter with olivary nucleus, this tract possibly constitutes an important pathway through which impulses from cortex and thalamus may reach the spinal cord.

6. **Descending medial longitudinal fasciculus.** The medial longitudinal fasciculus is originated from the medial vestibular nucleus, reticular formation, superior colliculus and the interstitial nucleus of Cajal. This bundle descend in the posterior part of the anterior funiculus of the spinal cord. This bundle is well defined only in the upper cervical segments of the spinal cord. Below these level this bundle is not so well defined but a few fibres have also been traced to lumbar level.

Function. Main functions of medial longitudinal fasciculus are the co-ordination of reflex ocular movements and integration of eye and neck movements.

Functions of extrapyramidal tracts

1. Corticonuclear (corticobulbar) fibres control the movements of the eyeballs.
2. All the other tracts are collectively responsible for *tone*, *posture* and *equilibrium*. [Rubrospinal tract—mainly tone and posture; Tectospinal—visuospinal reflexes; Vestibulospinal—equilibrium.]
3. They control complex movements of the body and limbs (*automatic associated acts*), such as co-ordinated movements of arms and legs during walking.
4. The cortex exerts tonic inhibitory control over the lower centres through these tracts. Damage to these tracts or ablation of area 6 causes increased rigidity of the muscles (Release phenomenon)—*vide* under *Hemisection of the spinal cord* (p. 5-139).
5. When pyramidal tracts are damaged, the extrapyramidal tracts may carry the volitional impulses to some extent.

INTERSEGMENTAL FIBRES

[Both Ascending and Descending Fibres]

Intersegmental fibres. These fibres are present for making connecting links among spinal segments at different levels. These fibres arising from the nerve cells of the gray matter of one segment descend or ascend at different levels and ultimately end around the cells of the same or of the opposite side. Such intersegmental fibres (Fig 5.112) are:

1. Ground bundle of anterior column or funiculus (Anterior intersegmental or Sulcomarginal fasciculus).
2. Ground bundle of lateral column or funiculus (Lateral intersegmental fasciculus).
3. Posterior column or funiculus consists of
   (*a*) Posterior intersegmental fasciculus (posterior ground bundle).
   (*b*) Septomarginal fasciculus:
   (*i*) Posterior septomarginal fibres. (*ii*) Dorsal peripheral strand. (*iii*) Oval bundle of Fleichsig. (*iv*) Triangular area of Phillippe-Gombault.

1. **Ground bundle of anterior funiculus (Anterior intersegmental or Sulcomarginal fasciculus).** This ground bundle connects the anterior horn cells of one side with those of the opposite side or of the same side at different levels of the spinal cord.

2. **Ground bundle of lateral funiculus (Lateral intersegmental fasciculus).** These fibres originating from the lateral horn cells ascend upwards into the medial longitudinal fasciculus.

3. **Posterior column or funiculus** are:

(*a*) **Posterior intersegmental fasciculus (Posterior ground bundle).** These fibres originating from the posterior horn cells connect different segments of the spinal cord.

(*b*) **Septomarginal fasciculus.** This fasciculus includes (*i*) the intersegmental fibres originating from the posterior horn cells connect with the corresponding posterior horn cells at lower levels, and (*ii*) the descending fibres of the medial division of posterior nerve roots.

(*i*) The septomarginal fibres present in the cervical and upper thoracic regions are commonly described as **posterior septomarginal fibres** or **comma tract of Schultze** (*vide* page 5-112).

(*ii*) The septomarginal fibres at lower thoracic regions are known as **dorsal peripheral strand.**

(*iii*) The fibres of the septomarginal fasciculus at lumbar segments are known as **oval bundle of Fleichsig (Fasciculus septomarginalis).**

(*iv*) The fibres of the septomarginal fasciculus in sacral segments lying against the posterior region of the median septum are called as **triangular area of Phillippe-Gombault.**

Effects of section of the anterior root

I. **Degenerative changes.** (1) Degeneration of peripheral portion, (2) degeneration of white rami communicantes up to the sympathetic ganglion, (3) chromatolysis of the anterior and lateral horn cells.

II. **Functional changes.** (1) Flaccid paralysis (lower motoneurone type) of the affected muscles, (2) loss of reflexes, (3) muscular wasting, (4) reaction of degeneration—present, (5) sympathetic paralysis.

Effects of section of the posterior root

I. **Degenerative changes.** (*a*) *If distal to the ganglion*—(1) degeneration of the peripheral fibres up to the receptor organs, (2) degeneration of the fibres of recurrent sensibility, (3) degeneration of the antidromic vasodilator fibres, and (4) chromatolysis of the ganglion cells. (*b*) *If proximal to the ganglion*—(1) degeneration of the tracts of Goll, of Burdach and of Lissauer and comma (descending) tract up to the next neurone, and (2) chromatolysis of the ganglion cells.

II. **Functional changes.** (1) Loss of all sensations, (2) incoordinated movements of the muscles due to loss of kinaesthetic sensations, (3) loss of muscle tone and reflexes, (4) trophic ulcers (due to loss of sensations), and (5) vasomotor disturbances due to degeneration of the antidromic vasodilator fibres.

Effects of section of the mixed spinal nerve

I. **Degenerative changes.** (1) Degeneration of the peripheral fibres (somatic and autonomic), (2) chromatolysis of the ganglion cells, anterior horn cells, lateral horn cells.

II. **Functional changes.** (1) Loss of all sensations, (2) complete paralysis of the lower motoneurone type, (3) trophic ulcers, (4) reaction of degeneration—present, (5) sympathetic paralysis and vasodilatation due to section of white rami communicantes to the sympathetic ganglion, (6) paralysis of sweat glands and pilomotor nerves, (7) vasodilatation followed by vasoconstriction, (8) loss of reflexes.

HEMISECTION OF THE SPINAL CORD

The term 'hemisection' is technically used to indicate a lesion involving one lateral half of the spinal cord. If it is due to an injury, a stage of **spinal shock** first appears, during which the subject may become unconscious, the muscles are all flaccid and reflexes abolished. In case the patient survives, this stage gradually passes off and typical features of the

lesion gradually develop. These features are very helpful in locating the site of injury. The typical features of spinal hemisection (FIG5.139) are as follows:

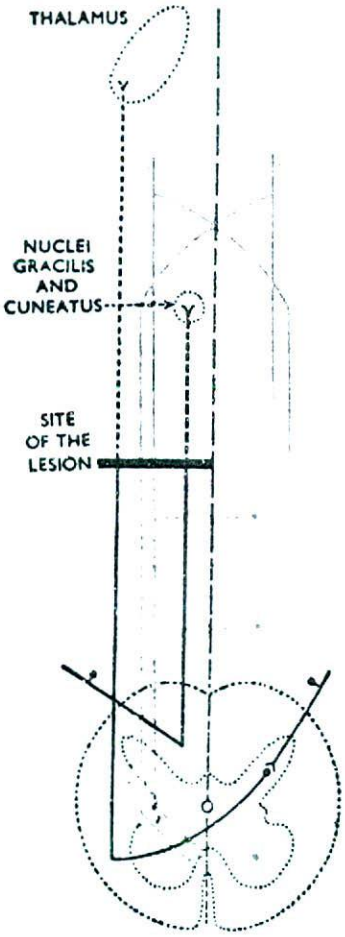


FIG.5.139. Showing the principal nerve tracts affected in hemisection.
Red = crossed and direct pyramidal tracts.
Black = tracts of Goll and of Burdach, and spinothalamic tract.

I. Degenerative changes

(1) The peripheral parts of the cut fibres degenerate up to the next neurone. (2) The central parts of the fibres and the related nerve cells may degenerate to a variable extent. (3) There may be transneuronal degeneration (*vide* page 5-161).

II. Functional changes

1. BELOW THE LEVEL OF SECTION

A. *SAME SIDE*

Sensory changes:

1. Fine touch, tactile localisation, tactile discrimination and kinaesthetic senses are lost. Caused by damage to the tracts of Goll and of Burdach.

2. Pain, temperature and crude touch remain unaffected. Because spinothalamic fibres cross to the opposite side below the level of section and are, therefore, not affected.

Motor changes:

1. Extensive paralysis of the **upper motoneurone type,** caused by damage to the crossed pyramidal tracts. Since some fibres of the direct pyramidal tract of the opposite side (which end in the same side) may escape, some muscles on the side of the lesion may not be paralysed. **Upper motoneurone paralysis has the following features:** (*a*) *Paralysed muscles are rigid due to increased tone* (*b*) *Deep reflexes—exaggerated.* (*c*) *Superficial reflexes—lost.* (*d*) *Babinski's sign—positive* (FIG.5.140). (*e*) *Muscles not much wasted.* (*f*) *Reaction of degeneration* (*R.D.*) *absent.*

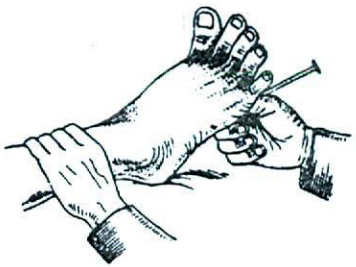


FIG. 5.140. Babinski's sign.

2. **Vasomotor.** Temporary loss of vasomotor tone due to damage to the fibres coming down to the lateral horn cells from the vasomotor centre in the medulla. The blood vessels are dilated and the skin may be congested. But later on the intact lateral horn cells will start acting as *subsidiary vasomotor centres* and the tone returns.

B. *OPPOSITE SIDE*

Sensory changes:

1. Complete loss of pain, temperature and crude touch. Caused by injury to the spinothalamic fibres which come from the opposite side and are caught up in the lesion.

2. Kinaesthetic sensations, fine touch, etc., will persist. Because the posterior column tracts of the opposite side are not injured.

Motor changes:

Either no paralysis or paralysis of a few muscles only. The latter is due to the possible involvement of some fibres of the direct pyramidal tract of the same side and these fibres cross ultimately to the opposite side. The paralysis will be of upper motoneurone type.

Analysing the above findings it will be seen that below the level of section there is extensive sensory loss, but little motor loss on the opposite side. While on the same side there will be extensive motor loss but little sensory loss. This phenomenon is known as **Brown-Sequard syndrome.**

2. AT THE LEVEL OF SECTION

A. *SAME SIDE*

Sensory changes:

Complete anaesthesia, because the posterior nerve root, the posterior horn cells and the spinothalamic fibres—crossing to the opposite side—are all lost.

Motor changes:

1. Complete paralysis of the **lower motoneurone type** caused by damage to the anterior horn cells. **Lower motoneurone paralysis** has the following features: (*a*) *Paralysed muscles are flaccid—due to loss of tone.* (*b*) *All reflexes—superficial and deep—are lost.* (*c*) *Muscles degenerate and undergo wasting.* (*d*) *Reaction of degeneration—present* (A.C.C. > C.C.C.).

2. **Vasomotor.** Complete and permanent vasomotor paralysis caused by injury to the lateral horn cells.

B. *OPPOSITE SIDE*

Sensory changes:

There may be some loss of pain sensation, because the pain fibres of the spinothalamic tract cross horizontally in the same segment and may be caught up in the lesion.

Motor changes:

Nil or very slight—due to damage to some direct pyramidal fibres of the same side.

3. ABOVE THE LEVEL OF SECTION

A. *SAME SIDE*

There will be a band of hyperaesthesia, possibly due to irritation of the upper cut ends of the damaged fibres.

B. *OPPOSITE SIDE*

Hyperaesthesia may be referred.

Regional peculiarities of hemisection of the spinal cord at different levels

The above description holds good for every case of hemisection, but certain characteristic features will be present according to the particular region involved.

1. **In the cervical region.** There will be the following three additional features:

(*a*) Constriction of pupil on the same side. Because the pupil-dilating fibres, which come from medulla and pass out through the first, second and third thoracic anterior roots, are involved. [Same change will take place if the upper three thoracic segments are involved.]

(*b*) If the fourth, fifth and sixth cervicals are involved, there will be loss of biceps, triceps, supinator and pronator jerks.

(*c*) Paralysis of the same side of the diaphragm, due to involvement of the phrenic nerve (4, 5, 6 cervical).

2. **In the lumbar region.** If it involves the third and fourth lumbar, the additional features will be: (*a*) Loss of knee jerk. (*b*) Some disturbance of micturition.

3. **In the lumbosacral region.** The additional feature will be loss of the sphincter control.

APPLIED CONSIDERATIONS ON SPINAL TRANSECTIONS

The motor and sensory changes described above indicate the broad principles of physiological changes that take place in different types of 'transection' of spinal cord. The term **incomplete transection** *is used to indicate a partial lesion involving both sides of the spinal cord.* In such cases some of the extrapyramidal tracts (specially vestibulospinal) escape and thus the brain stem still exerts its control over the anterior horn cells. Whatever the type of spinal transection may be, the subject may have the following three stages: (1) **stage of spinal shock,** (2) **stage of reflex activity,** (3) **stage of reflex failure.** *The first and the third stages are more or less same in both incomplete and complete transections, but remarkable differences are found in the second stage between incomplete and complete transections.* The clinical manifestations of complete transection and its differences with incomplete transection are as follows:

Complete transection of the spinal cord

1. **Stage of spinal shock (Stage of flaccidity).** A period comes when all spinal reflex responses are depressed in association with or without consciousness depending upon the extensiveness of the damage. Gradually the reflex responses return and become relatively hyperactive. Below the level of section (*a*) muscles are paralysed and flaccid. (*b*) All reflexes lost. (*c*) Sphincters are at first paralysed but quickly regains tone causing retention of urine. (*d*) If above second lumbar, fall of blood pressure due to vasomotor damage. (*e*) Absence of movements and vascular tone in the paralysed parts reduces circulation causing stagnation. Hence, slight pressure may cause oedema, and nutrition of the limb suffers. Skin becomes cold, blue and liable to bedsores.

Higher the animal, more profound and lasting will be the effect of spinal shock, viz., in rats—a few minutes, in monkey—a few days, and in

man—about three weeks. Because, in higher animals the spinal cord is more under the influence of higher centres. *The phenomenon of spinal shock points out that the whole nervous system works as a single unit. Changes in one part affect the activities of distant regions* **(Diaschisis).**

The cause of spinal shock is not known, perhaps related with the cessation of tonic neuronal discharges from the upper brain stem or supraspinal pathways.

2. **Stage of reflex activity (Stage of recovery).** It is associated with reflex excitability. The first reflex response reappeared in man is slight contraction of flexor and adduction to noxious stimuli. The knee jerk often comes back first.

3. **Stage of reflex failure.** The isolated cord has less power of resistance. In case any toxaemia or infection develops, reflex functions gradually fail, viz., (*a*) The reflexes become more difficult to elicit. (*b*) The stimulus threshold raised. (*c*) Mass reflexes abolished. (*d*) Muscles become flaccid and undergo wasting. (*e*) Bedsores develop. (*f*) Cystitis and paralysis of urinary sphincters. Hypercalcaemia leading to hypercalcinuria (hypercalcuria) which predisposes to urinary infection. The termination of such cases takes place through septicaemia, uraemia, inanition, etc.

Incomplete transection of the spinal cord

As mentioned above the manifestations of the first and third stages are same as those of *complete transection*. But in the second stage (stage of reflex activity) *incomplete transection* shows certain characteristic features, quite distinct from those of complete transection.

In incomplete transection, some extrapyramidal tracts escape, so that the influence of brain stem on the cord is maintained. But in complete transection the cord below the level of lesion is cut off from the higher centres.

The chief distinctive features of the two types, as seen in the **stage of reflex activity** (second stage), are noted below:

COMPLETE TRANSECTION	INCOMPLETE TRANSECTION
1. **Smooth muscles**—function returns first. Hence, (*a*) retention of urine due to sphincter action, (*b*) blood vessels regain tone, (*c*) blood pressure rises.	1. **Smooth muscles**—function returns first. Hence, (*a*) retention of urine due to sphincter action, (*b*) blood vessels regain tone, (*c*) blood pressure rises.
2. **Voluntary muscles**—tone of the flexor muscles returns after 2–3 weeks causing *paraplegia* in flexion (FIG. 5.141). Hip and knee flexed. Ankle and toes dorsiflexed.	2. **Voluntary muscles**—tone of the extensor muscles returns causing *paraplegia* (FIG. 5.141). in extension. Hip and knee extended; ankle and toes plantarflexed.
3. **Reflex movements** (*a*) **Spontaneous flexion** movements—early and frequent.	3. **Reflex movements** (*a*) **Spontaneous extension** movements—early but infrequent.
(*b*) **Flexor reflexes—return first.** A painful stimulus on the sole will elicit it—hip and knee flexed, ankle and big toe dorsiflexed. Other toes abducted and may be dorsiflexed. [Sometimes plantarflexed.] This movement is obviously a protective *withdrawal reflex*, away from the cause	(*b*) **Flexor reflexes—return later.** Can be weakly elicited by similar painful stimuli, usually accompanied by extension of the opposite limb (**crossed extensor reflex**). Gentle flexion of one limb causes extension of the opposite limb (**Phillipson's reflex**). Then the

COMPLETE TRANSECTION	INCOMPLETE TRANSECTION
of injury. In spinal animals the flexor reflex spreads to the extensor muscles of the opposite side causing *crossed extensor reflex*, but in man it remains either limited to the limb concerned or produces flexion of the opposite limb.	flexed limb becomes extended and the other one flexed. In this way, the movement alternates in the limbs producing a *stepping movement*. This shows that in incomplete transection *the range of reflex activity is greater* and movements of locomotion can be carried out to some extent reflexly and unconsiously by the lower parts of the central nervous system.
(*c*) **Extensor reflexes** (Deep reflexes) — **return much later**. difficult to elicit. *Extensor reflex never obtained*. Knee jerk returns 1-5 weeks after the flexor reflex (*relaxation sudden and complete due to absence of* quardriceps tone). Ankle jerk returns still later.	(*c*) **Extensor reflexes return much early** and easy to elicit. Knee jerk shows prolonged period of relaxation due to higher quardriceps tone. *Extensor thrust reflex is constantly present and is diagnostic* (with the legs flexed, if foot is pressed, contraction of quadriceps and posterior calc muscles).
(*d*) **Mass reflex** — sometimes a wide spread reflex may be elicited by scratching any area below the section, such as flexor spasm of the lower limbs and contraction of the abdominal wall, evacuation of the bladder, profuse sweating, etc.	(*d*) **Mass reflex** — usually not much because the controlling effect of the brain stem persists.

As commonly seen in civil practice, a slow inflammator disease of the spine (tubercular) or a tumour will exert gradually increasing compression on the spinal cord producing at first hemisection, then incomplete transection and lastly, complete transection. Hence, the features of one will gradually merge into those of other.

Spinal animal. [Animal with transection of the spinal cord.] The animal will have the same three stages as in man : Stage of spinal shock is less in intensity and duration. A monkey with thoracic cord cut will go on catching flies. In the second stage there will be paraplegia in flexion, and crossed extensor reflex [*vide* p5-142) under 3(*b*)]. *Extensor thrust reflex* will be regularly obtained, because the cord has control on the extensor arcs (in man only found in incomplete transection). Spinal animal also shows presence of scratch reflex and mark-time (locomotion) reflex.

EFFECTS OF LESIONS AT VARIOUS LEVELS OF THE CENTRAL NERVOUS SYSTEM (Fig. 5.14.)

Massive lesion of cerebral cortex may cause *hemiplegia, monoplegia* depending upon the extent of damage. If the internal capsule is lesioned then *contralateral hemihypoesthesia*, and even *homonymous hemianopia* as well as *hemiplegia* may occur. Unilateral lesion of midbrain involving the oculomotor (III cranial) nerve may cause, beides *contralateral spastic hemiplegia, ptosis* of upper eyelid, paralysis of ocular muscle, dilatation of the pupil along with loss of pupillary light reflex. Lesion in pons involving facial (VII cranial) nerve and also the descending motor fibres will cause *crossed hemiplegia* along with homolateral facial paralysis. Lesion in the medulla

oblongata destroying the descending motor tracts and hypoglossal (XII cranial) nerve cause *crossed hemiplegia* and homolateral paralysis of lingual muscles. Complete transection of the spinal cord involving all the descending and ascending tracts causes *paraplegia.*

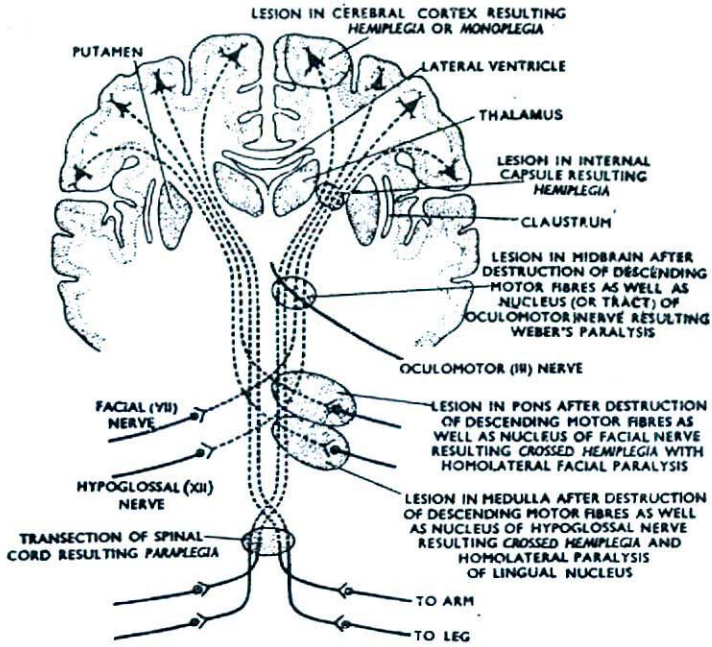


FIG. 5.141. Diagram represents the effects of lesions at various levels of central nervous system.

LEMNISCUS OR FILLET

Definition. Any prominent nerve tract formed by crossed sensory fibres in the central nervous system.

Varieties. There are four fillets: (1) **Spinal lemniscus or spinal fillet**—same as the spinothalamic tract. (2) **Trigeminal lemniscus or trigeminal fillet**—formed by the crossed fibres arising from the sensory nuclei of the trigeminal nerve. Carries general senses from head, neck, face, mouth, eyeballs and ears. (3) **Lateral lemniscus or lateral fillet**—formed by the second neurones in the auditory pathways (*vide Path of hearing*). (4) **Mesial lemniscus or mesial** (medial) **fillet**—formed by (*a*) spinal lemniscus or spinal fillet, (*b*) internal arcuate fibres, (*c*) trigeminal lemniscus or trigeminal fillet, (*d*) fibres from the sensory nuclei of other cranial nerves, specially seventh (taste), ninth, tenth (respiratory passages) and vestibular impulses. It passes through the midbrain in the tegmentum and ends in the lateral nucleus of the thalamus. Carries general sensations from the whole body, also taste and vestibular impulses. Hence, in the upper part of brain stem, there are only two lemnisci or fillets—lateral and medial. Except the lateral lemniscus or fillet, almost all other sensory fibres merge in the medial lemniscus or fillet.

THE BRAIN STEM

The brain stem (Figs. 5.11 & 142). frequently includes the midbrain containing the cerebral and cerebellar peduncles, corpora quadrigemina, red nucleus, etc., the medulla oblongata (spinal bulb), and pons varolii.

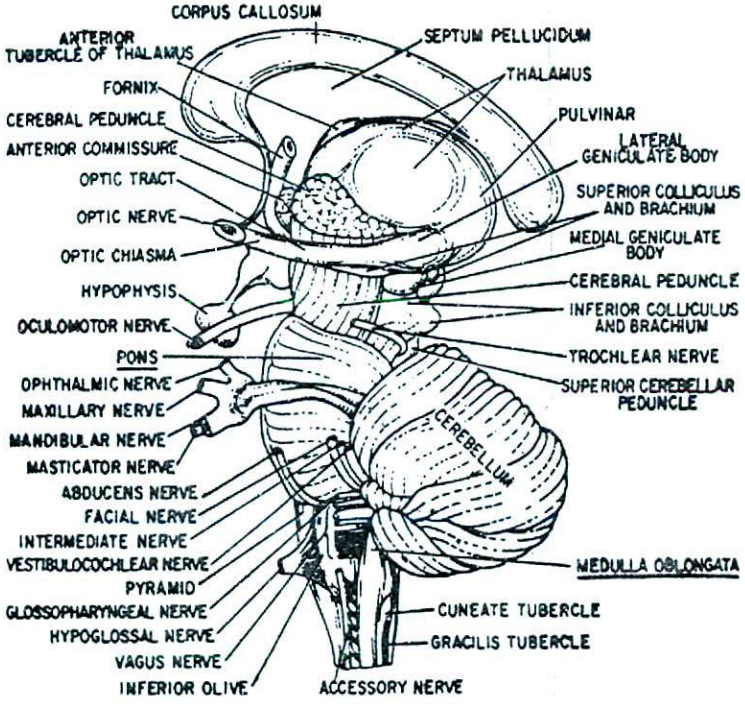


Fig. 5.142. Diagrammatic representation of the lateral view of the brain stem and relationship of attached cranial nerves.

Midbrain (Mesencephalon)

The midbrain connects the forebrain with the hindbrain. Its dorsal part includes four rounded eminences, called the corpora quadrigemina (superior and inferior colliculi) which contain important correlation centres and also nuclei concerned with motor co-ordination. Its ventral part consists of a pair of cylindrical bodies, called the cerebral peduncles, which are great masses, commonly of white matter, uniting the pons with the thalamic region of the cerebrum. Between the ventral and the dorsal part there is the cerebral aqueduct (aqueduct of Sylvius) which is surrounded ventrally and laterally by the nuclei of origin of the oculomotor nerves (Figs.5.143, 144 & 146). From before backwards, the cerebral peduncles consist of the following parts :

(*a*) **Basis pedunculi** are made up largely of the descending and ascending fibre tracts from the cerebrum above, and the cerebellum, medulla and spinal cord below (Fig. 5.145).The pyramidal tracts occupy

the middle three-fifths of the basis pedunculi, the frontopontine and corticonuclear fibres occupy the medial one-fifth and the lateral one-fifth is occupied by temporopontine tract.

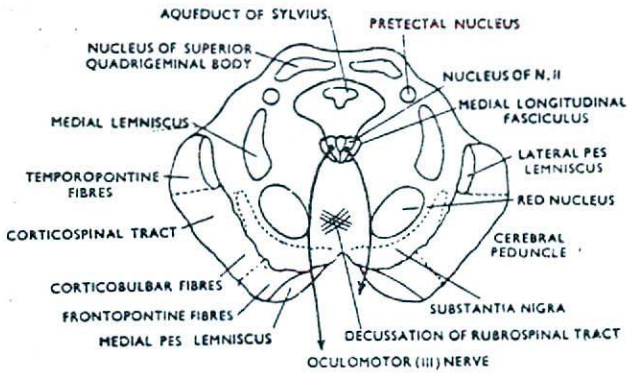


FIG. 5.143. Schematic transverse section through upper part of the midbrain. The pretectal nucleus is actually rostral to the plane of the section. The reticular formation occupies the space between the substantia nigra and central gray matter.

(*b*) **Substantia nigra.** This is the most voluminous mass of deeply pigmented cells, extending the whole length of the midbrain and projecting into the caudal diencephalon. Though its function is debatable, the substantia nigra is regarded as an important extrapyramidal or non-pyramidal nucleus, largely because it is one of the structures of this system that is consistently affected in paralysis agitans. According to Jung and Hassler,

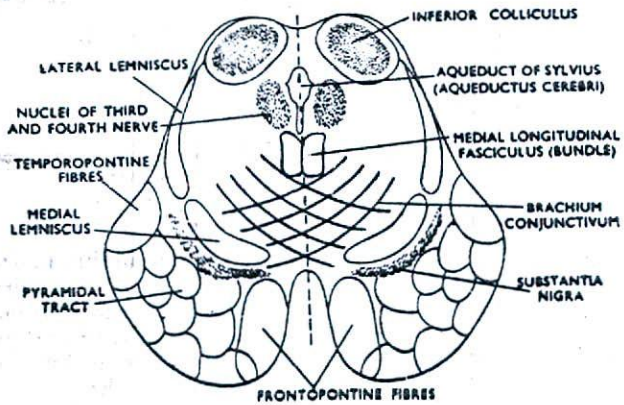


FIG. 5.144. It shows a section through the midbrain at the level of inferior colliculus.

the rigidity and akinesia of the Parkinsonian syndrome probably are caused by lesions involving the substantia nigra. Degenerative changes in this nucleus may impair semiautomatic associative movements which normally accompany voluntary movements, such as swinging of the arms during walking.

(*c*) **Tegmentum.** The narrow aqueduct, somewhat triangular in

section, is surrounded by a broad layer of central gray matter that is poor in myelinated fibres, and contains numerous diffusely grouped cells. From below upwards, three decussations take place within it which have dentatothalamic fibres, the rubroreticulospinal tracts and the tectospinal tracts.

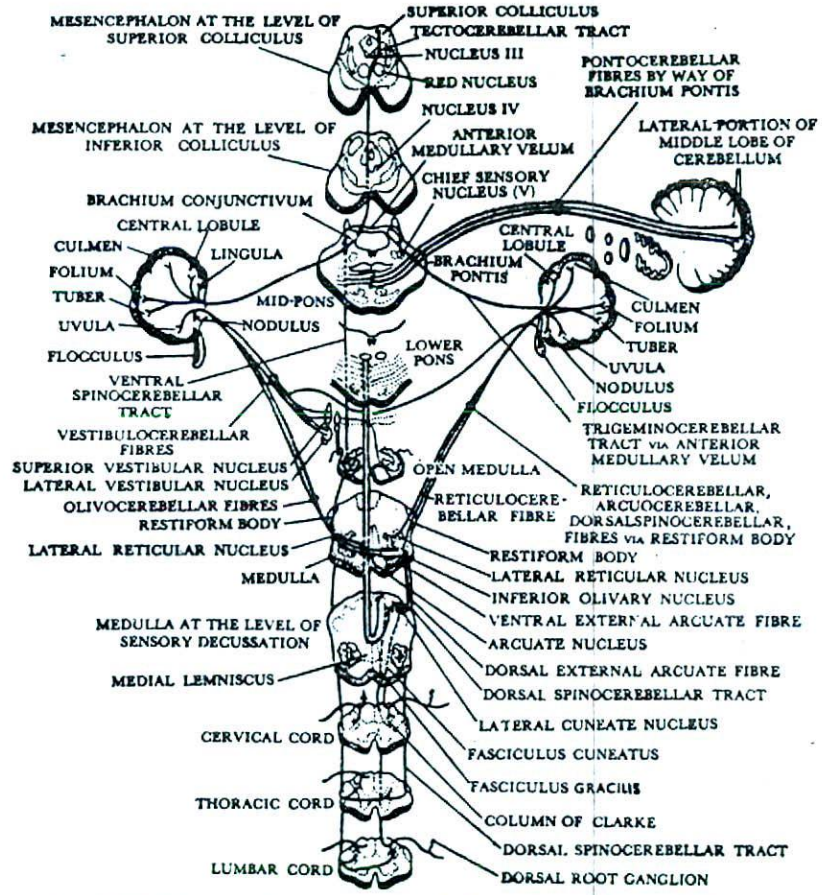


FIG. 5.145. Diagrammatic representation of afferent fibres of the cerebellum from the midbrain, pons, medulla and spinal cord.

The **nucleus ruber** or **red nucleus** consists of two groups of cells: nucleus magnocellularis and nucleus parvocellularis. The former group comprises the caudal one-third of the whole nucleus and is made up of large nerve cells which give rise to the rubrospinal tract. The latter group consists of small nerve cells and comprises the cranial two-thirds of the red nucleus. The red nucleus extends from the hypothalamus to the caudal border of the superior colliculi (FIG. 5.146). In the human being, the large cells are few and the rubrospinal tract is small. A rubroreticular tract arises from most of the cells of the nucleus and ends in the reticular gray matter in the brain stem. From here the impulses are transmitted to

the spinal cord through reticulospinal fibres. In small mammals, the red nucleus plays an important role in helping to maintain normal body posture and normal muscle tone by means of its afferents from cerebellum, vestibule and muscles, and from its efferent rubrospinal and rubroreticular fibres. This nucleus is 0·5 cm in diameter and a centre for righting reflex.

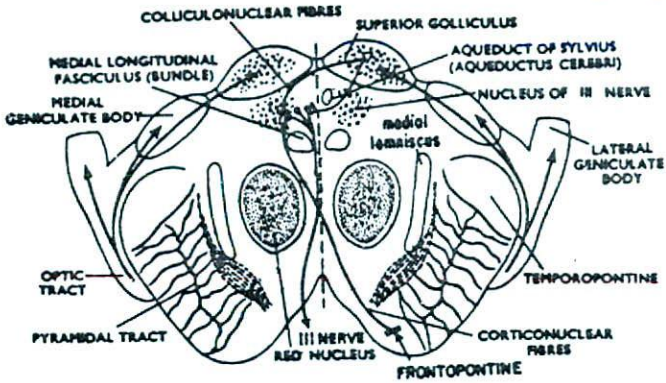


FIG. 5.146. Diagram represents a section through the midbrain at the level of superior colliculus.

The superior colliculi are responsible for visual reflexes and reflexly alter the position of the trunk, head, eyes and limbs in response to retinal impulses by means of the tectospinal tract. This tract connects the superior colliculi with the pupil-dilator centre in the thoracic cord (T. 1 and T. 2). Passing to the oculomotor nuclei, colliculonuclear tract produces constriction of the pupil during light reflex.

The oculomotor nerve (III) arises from a nucleus in the floor of the cerebral aqueduct. The fibres of the motor root of the trigeminal or trifacial nerve (V) arise from two nuclei, a superior, located in the cerebral aqueduct, and an inferior, located in the upper part of the pons. It is debatable whether the fibres from the superior nucleus are afferent or efferent.

Pons varolii

Anatomy. It is a thickening located above the medulla oblongata. It appears anteriorly as a bulging mass of transverse fibres and is separated from the cerebellum posteriorly by the IV ventricle. The prominent internal feature of the pons is the presence of transversely crossing bundles of the brachium pontis (middle cerebellar peduncle). These bundles run from the pons to the opposite cerebellar hemisphere and *vice versa*, and break up the pyramidal tract into scattered groups of fibres where the nucleus pontis lies with small masses of gray substance. The medial lemniscus is connected by central fibres from the sensory nuclei of V, VII, IX and X nerves (FIGS. 5.147 & 5.148

The IV ventricle becomes narrow gradually in the cerebral aqueduct at the upper region of the pons. Above it on either side the brachia conjunctiva (superior cerebellar peduncles) appear. Though the peduncles arise commonly from the dentate nucleus of the cerebellum, yet these two masses of longitudinally running fibres which pass forward approach the

midline, and reach the nucleus of the opposite side after decussation and then the thalamus headwards. The ventral spinocerebellar tract enters

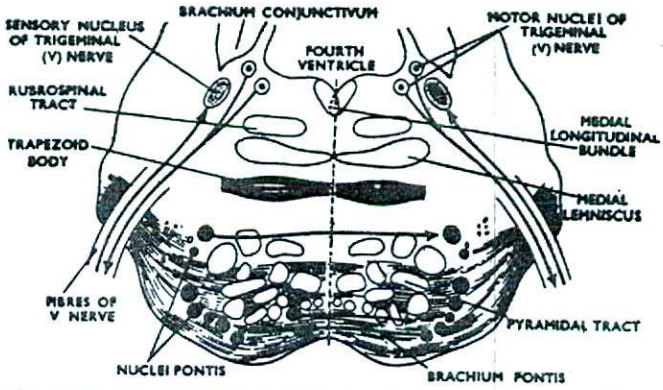


FIG. 5.147. Diagrammatic representation of a section through the upper part of pons varolii.

the vermis of the cerebellum after turning over the lateral part of this peduncle.

In transverse section, two main portions in pons are visualised. The posterior or tegmental portion represents the cranial continuation of the reticular formation of the medulla. Within this tegmental portion the motor and sensory nuclei of cranial nerves (V, VI, VII and VIII) are present (FIG 5.142). The larger anterior or basilar portion of the pons is the transverse pontine fibres, pontine nuclei, and descending fibre bundle of the corticobulbar and corticospinal tracts. The corticospinal tract forms a compact bundle on each side at the lower end of the pons and forms the pyramid of the medulla.

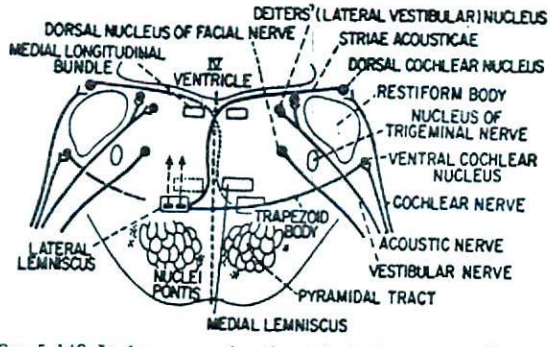


FIG. 5.148. It shows a section through the lower part of pons.

Function. Pons is primarily concerned with the maintenance of normal rhythm of respiration. Different experimental studies have led to the conclusion that pons has got two separate respiratory centres—the pneumotaxic centre and apneustic centre. The pneumotaxic centre is situated in the upper pons and is the dominant part. It controls the exaggerated activity of the apneustic centre and thereby produces a rhythmical respiratory activity characteristic of normal respiration (*vide* volume I)

It is of opinion (Wang *et al*, 1964) that the apneustic centre is situated in the caudal margin of the trapezoid body—the border between the pons and the medulla. The apneustic centre is under the inhibitory control of both the vagus nerves and the pneumotaxic centre.

Medulla oblongata (Spinal bulb)

Anatomy. Medulla is a conically expanded continuation of the cervical spinal cord and is extended from the foramen magnum to the caudal border of the pons. It is approximately 28 mm in length. Its transverse diameter of the foramen magnum is 9–12 mm and near the pons is about 24 mm. Sulci which are present on the surface of the spinal cord are also continued upward into the medulla.

A section at the level of the lower third of the medulla oblongata shows a decussation of the pyramidal tracts (Fig.5.129)which pass from the ventral part of the medulla through the base of the ventral horn of gray matter. Then the tracts come to lie in the lateral columns where they

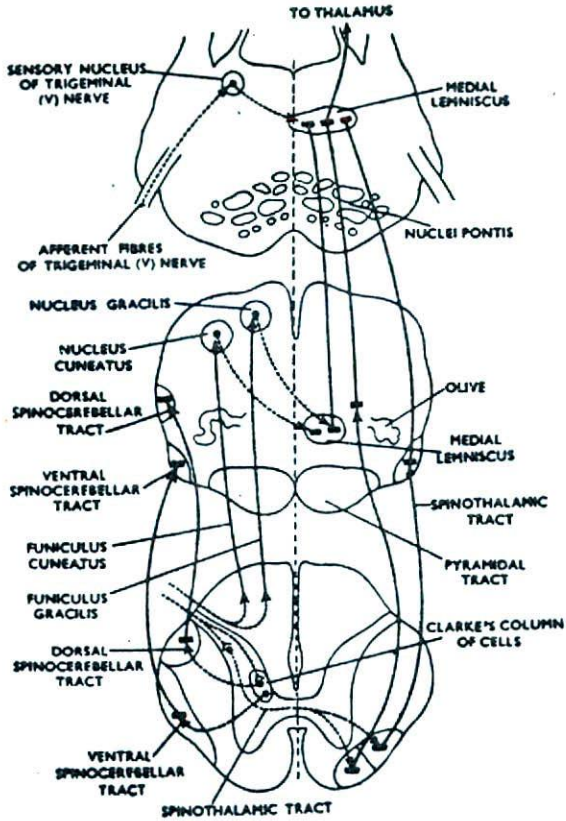


Fig.5.149. Diagrammatic representation of the course of ascending tracts.

descend into the spinal cord. The wider dorsal columns push the dorsal horns of gray matter apart from the pons to upper cervical region. On either side of the ventrolateral region there are rubrospinal tract, the spinothalamic tract and the dorsal and ventral spinocerebellar tracts (Fig. 5.149).

A section through the olive shows that the central canal approaches

the dorsal surface of the medulla oblongata and appears approximately at the calamus scriptorius into the IV ventricle. The funiculus gracilis ending in the nucleus gracilis and the funiculus cuneatus ending in the nucleus cuneatus replace the dorsal columns. A new relay station arises from the nuclear cells of the gracilis and cuneatus. Most of the fibres cross internal arcuate fibres to lie dorsal to the pyramid as medial lemniscus and a certain number of fibres pass the restiform body of both sides (FIG5.150).

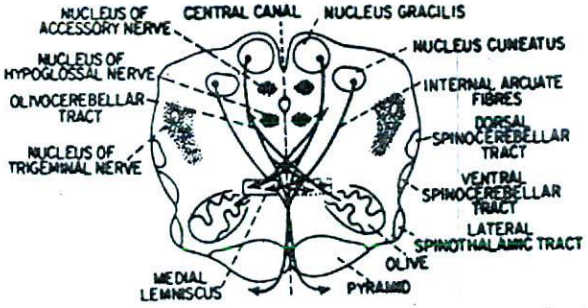


FIG. 5.150. Diagram shows a section through the medulla at the level of olivary nucleus.

Cardiac, vasomotor, vomiting, deglutition centres, etc., lie in the floor of the IVth ventricle at the level of the calamus scriptorius and near the dorsal nucleus of the vagus. In the medullary and pontine reticular formation the respiratory centres are situated.

The olive contains a wavy layer of gray matter. Though the olivary function is not clear, the olive gives rise to the (descending) bulbospinal tract. The ventral spinothalamic fibres migrate medially lying dorsolaterally to the medial lemniscus and the lateral spinothalamic fibres remain lateral to the olive.

NUCLEI OF THE VII IX, X, XI AND XII CRANIAL NERVES (FIGS.5.151,152& 153)

The motor somatic fibres of the hypoglossal (XII) nerves lie near the midline of the medulla.

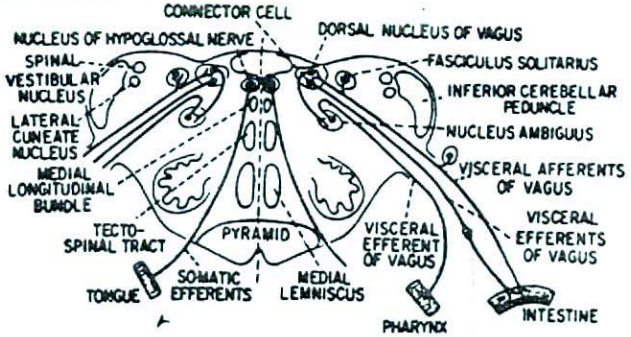


FIG. 5.151. A section through the upper region of the medulla oblongata showing origin of the vagus (X) and hypoglossal (XII) nerves (diagrammatic).

The ascending afferent fibres of facial (VII), glossopharyngeal (IX) and vagus (X) nerves are situated lateral to the nucleus of XII. The

descending afferent fibres of VII, IX and X nerves, which end in gray matter, lie in the fasciculus (tractus) solitarius and its nucleus. The somatic

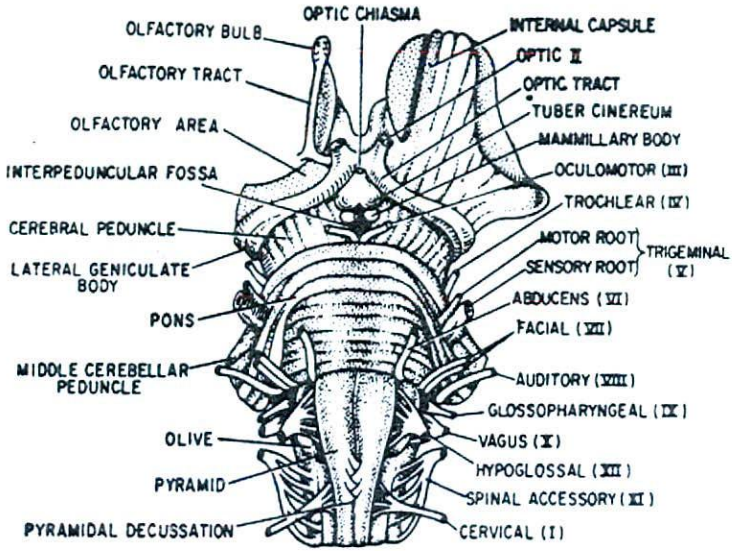


FIG. 5.152. Diagrammatic representation of the anterior view of the brain stem and attached cranial nerves.

efferent fibres of VII, IX, X and spinal accessory (XI) nerves arise from a column of cells which extend from the lower border of pons to C.5 and

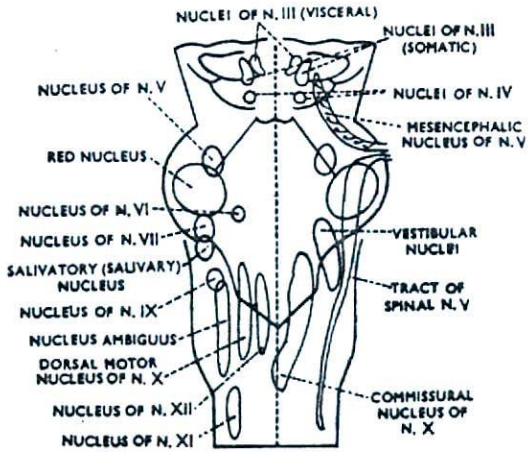


FIG. 5.153. Diagrammatic representation of nuclei of origin of cranial nerves on the posterior surface of the brain stem.

lie lateral and ventral to the column of dorsal nuclei. Autonomic efferent fibres of VII, IX and X arise in the column of the dorsal nuclei.

The cochlear nerve or nerve of hearing of the auditory nerve (VIII) passes dorsal to and the vestibular nerve ventral to the restiform body. The dorsal cochlear nucleus lies on the dorsolateral aspect of the restiform body and the ventral cochlear nucleus is situated between the cochlear and the vestibular nerve. From the dorsal cochlear nucleus the striae acousticae cross in the floor of the IV ventricle, and from the ventral cochlear nucleus the trapezoid body traverses the pons. The striae acousticae and trapezoid body turn up as the lateral lemniscus which is situated lateral to the medial lemniscus. The vestibular division of the VIII nerve ends in the vestibular nuclei (FIG. 5.151).

Function of medulla oblongata

CONTROL OF CARDIOVASCULAR FUNCTION. That the integrity of medullary structures is essential for the maintenance of normal cardiovascular tone, was first observed by Dittmar (1870), Owsjannikow (1871) and also others of the Ludwig school in Germany. Dittmar (1873) showed that if the brain stem is gradually sectioned from above downwards then a fall in arterial blood pressure is observed after transection

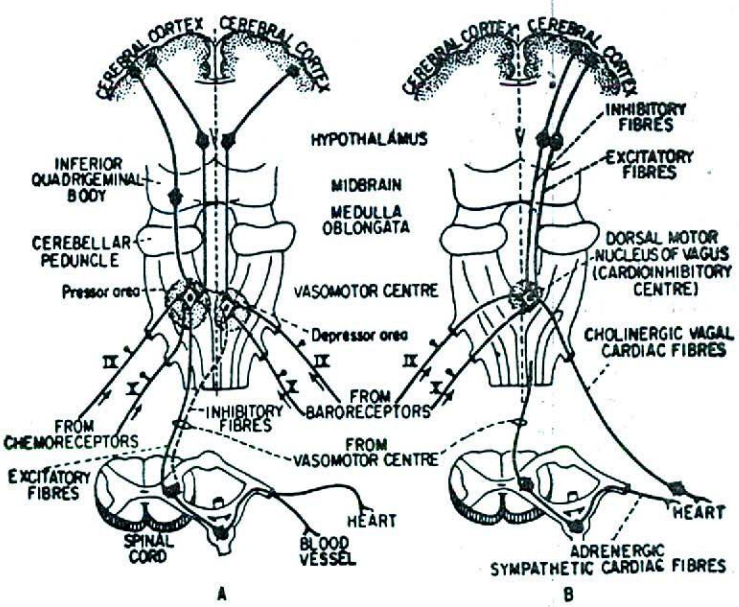


FIG. 5.154. Simplified diagram showing the cardiovascular regulating mechanism by the medulla with the help of autonomic innervations. 'A' represents blood pressure vasomotor controlling mechanisms. 'B' represents cardiac controlling mechanism.

in the middle of the pons. If the transections are progressed further downwards then greater falls are observed when the upper part of the medulla is reached. These findings led to indicate that the medulla is responsible at least for maintaining the vasoconstrictor tone. As early as 1901, Bayliss first introduced his dualistic theory that medullary centre might be responsible for controlling the both vasoconstriction and vasodilatation

and for these there might have been separate centre for each. These two centres act reciprocally and are thought to be tonically active.

Rosson and Billingsley (1916) showed that both pressor and depressor responses could be elicited by stimulation of the flow of the IV ventricle in cats. Alexander (1946) has shown that the pressor area comprises in extensive zone within the lateral reticular formation, with its principal extension in the rostral two-thirds of the bulb. A depressor area is localised to the medial reticular formation and extends chiefly into the caudal end of the bulb. Tonic activities of the pressor and depressor areas have been demonstrated by Alexander (1946). Pressor area exhibits continuous accelerator tonic discharge in the inferior cardiac nerves. Similarly the depressor area also exhibits a continuous inhibitory influence of the spinal cardiovascular neurone (FIG. 5.154).

The functional integrity of the medullary vasomotor area subserving the pressor and depressor reflexes is mostly dependent upon the relative functional activities of the specific systemic baro- and chemo-receptors. Pressor and depressor reflexes are also elicited by stimulation of various afferent somatic nerves and these reflexes are partly mediated through the medulla oblongata like pressor and depressor areas. The heart rate has been considered to be under the control of two centres—the medullary accelerator centre and medullary inhibitor centre. The accelerator centre is believed to be located within the reticular structures of the pressor centre but the exact position is still unknown. The inhibitor centre is possibly located in areas which are in communication with the vagal nucleus and amygdaloid nucleus.

CONTROL OF RESPIRATION. The medullary respiratory centre has been found to have two parts located bilaterally. One is for inspiration and other for expiration (FIG. 5.155). The inspiratory centre is stimulated with the increase in CO_2 concentration of body fluid; frequency and depth of respiration are increased. Expiratory centre also acts in part by inhibiting the inspiratory centre. Regulation of the rhythmic respiration is dependent

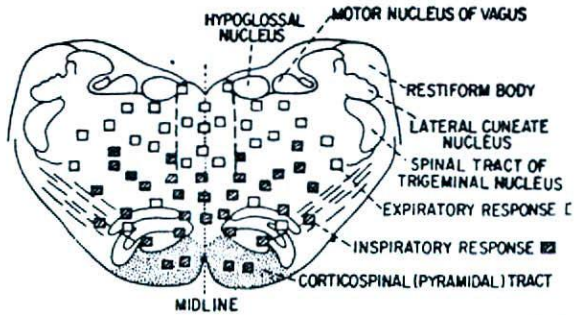


FIG. 5.155. Diagrammatic representation of a section through the medulla oblongata at the level of brachium conjunctivum (superior peduncle) with the distribution of inspiratory and expiratory centres.

upon the alternating activity of the two portions of the respiratory centre (*vide* VOL. I).

Besides these controlling functions of the medulla on respiratory and cardiovascular activity, the medulla has got other functions too. The

medulla is responsible for different visceral afferent and efferent mechanisms subserving various other reflexes. These are

1. coughing reflex,
2. sneezing reflex,
3. swallowing reflex,
4. salivary reflex,
5. sucking reflex,
6. vomiting reflex,
7. reflex hyperglycaemic effect.

Brook (1931) has observed that there is an area in the lower part of the medulla oblongata which when stimulated by incoming afferent volley causes rise of blood sugar.

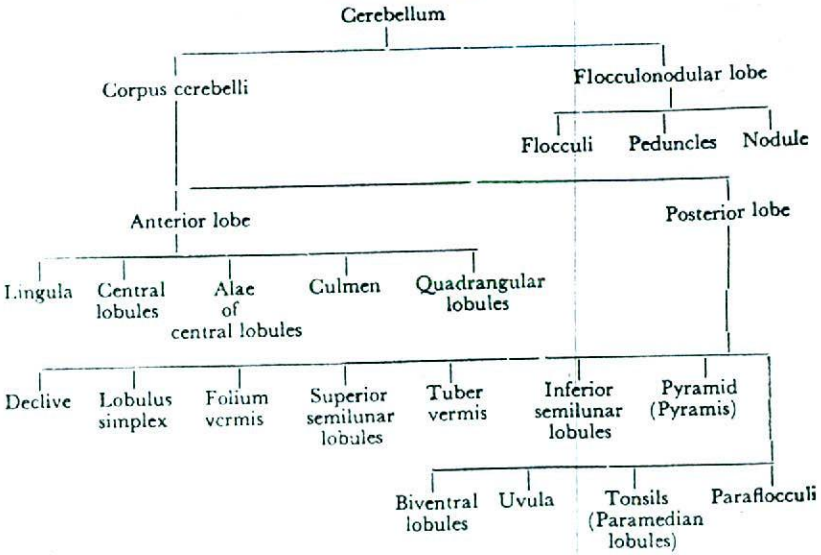
The medulla oblongata is a vitally important part of the central nervous system. Disturbances in the medulla oblongata may lead to death from respiratory and cardiac arrest.

Besides this the medullary reticular formation is also related with the posture and movement.

CEREBELLUM

Anatomy. *Cerebellum* is the largest part of the hindbrain and lies behind the pons and medulla oblongata. The median portion of the cerebellum is separated from the pons and medulla by the cavity of the IV ventricle (FIG. 5.156). Average weight of the cerebellum in the adult is approximately 150 gm and proportion between the cerebrum and the cerebellum is about 8 to 1, in the infant about 20 to 1.

FUNCTIONAL AND MORPHOLOGICAL SUBDIVISIONS OF CEREBELLUM



Functional subdivisions. In general form, the cerebellum consists of right and left cerebellar hemispheres joined by a narrow median strip the **vermis.**

From functional point of view, the cerebellum has been subdivided by Larsell and also by others into two fundamental parts: (1) **flocculonodular lobe,** and (2) **corpus cerebelli** (FIG. 5.157).

These subdivisions not only have got functional significance but of morphological and embryological significance. The *flocculonodular lobe* is separated from the corpus cerebelli by the *postero-lateral fissure.*

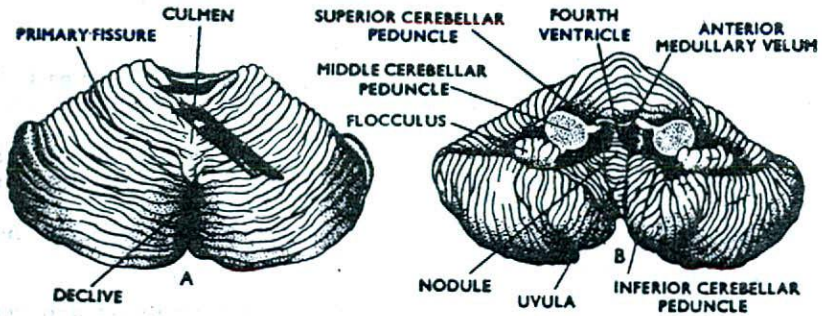


FIG. 5.156. Diagrammatic representation showing superior surface (A) and inferior surface (B) of the human cerebellum.

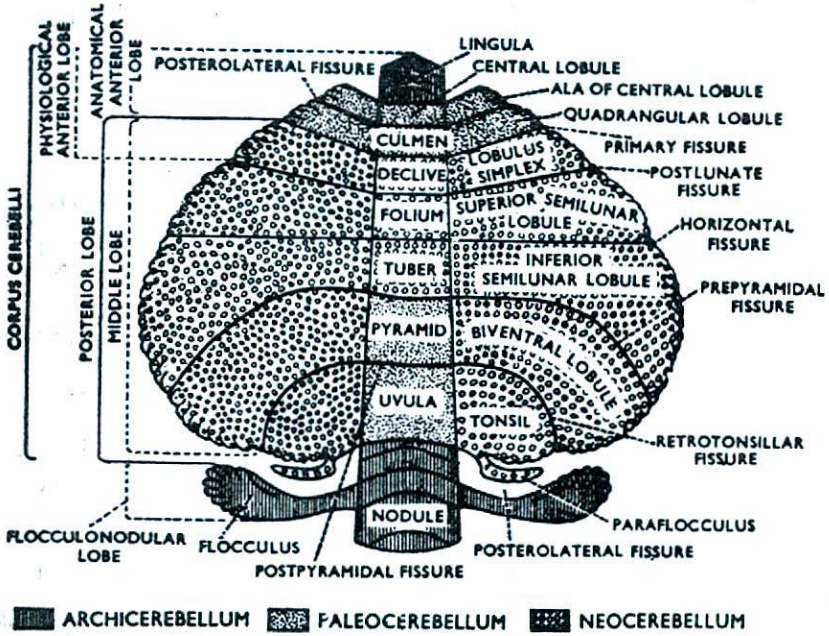


FIG. 5.157. Diagrammatic representation of the morphological and functional subdivisions of the cerebellum as seen from the superior surface.

The flocculonodular lobe consists of: (*i*) *flocculi*, (*ii*) their *peduncles*, and (*iii*) *nodule.*

The *corpus cerebelli* comprises the rest of the cerebellum and is further subdivided by *primary fissure* into *anterior lobe* and *middle lobe* by Ingvar or the *posterior lobe* by Larsell (FIGS.5.157& 159). Anatomically the *anterior lobe* is

situated in front of the primary fissure and includes the *lingula, central lobule, culmen, alae of the central lobules* and *quadrangular lobules*. But the *physiological anterior lobe* includes the *lobulus simplex* and *declive* in addition. Anatomically the *middle lobe* includes the *declive, folium vermis, tuber vermis, pyramid, uvula, lobulus simplex, biventral lobules, superior semilunar lobules, inferior semilunar*

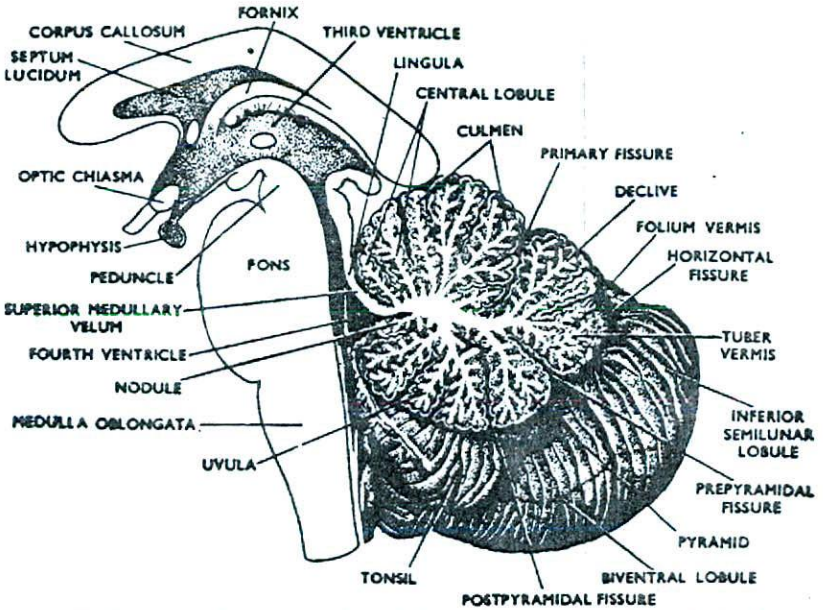


FIG. 5 158. Diagrammatic representation of the median sagittal section of the cerebellum showing principal lobules by name and showing also brain stem.

lobules and *tonsils*. But the *posterior lobe* of Larsell includes the whole of the *middle lobe* as described above and the paraflocculus in addition (FIGS. 5.157,158 & 159).

In many mammals, the **paraflocculus** has been originated from the portion of cerebellar hemisphere. It is not yet confirmed whether the paraflocculus is present in human cerebellum. It has got a little functional relation with flocculus and derives its afferent connections mostly from the cerebral cortex.

Phylogenetic subdivisions. Phylogenetically, the cerebellum has been divided into three parts: (*a*) *archicerebellum*, (*b*) *palaeocerebellum*, and (*c*) *neocerebellum* (FIGS 5.157&159).

Archicerebellum. Archicerebellum consists of the flocculonodular lobe together with lingula, i.e., *nodule*, both *flocculi* with their *peduncles*, and *lingula*. The flocculonodular lobe is exclusively vestibular in its connections, but together with lingula there are also spinocerebellar connections in addition to vestibular connections.

Palaeocerebellum. It is longer than the archicerebellum but smaller than the neocerebellum. It is constituted with the anterior lobe excepting lingula, but together with pyramid and uvula. So it consists of

central lobule, alae of central lobule, culmen, quadrangular lobule, uvula and the *pyramid on the ventral aspect.* It is mainly spinocerebellar in its connections.

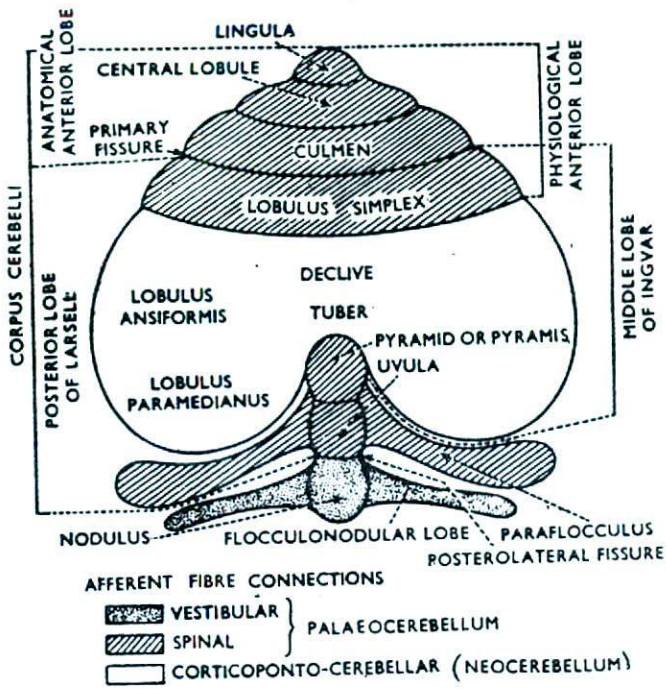
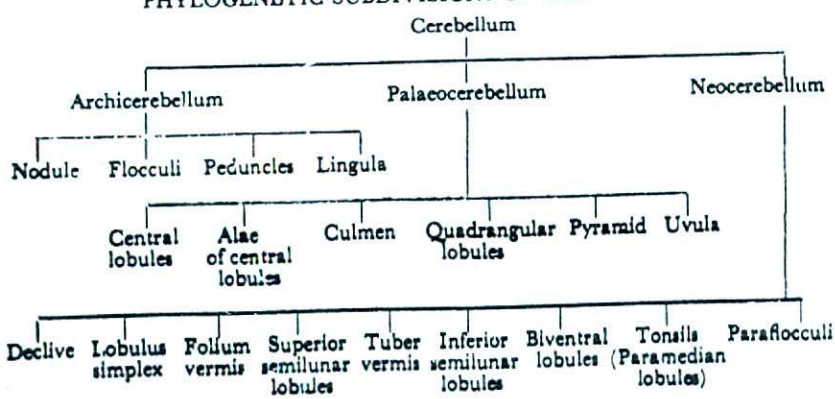


FIG. 5.159. Schematic representation of principal divisions of the cerebellum of the Macaque showing afferent connections (*modified after Best & Taylor*).

Neocerebellum. It is the largest and includes the whole of the posterior lobe with the *exception of the pyramid and the uvula.* It is predominantly corticopontocerebellar in its connections.

PHYLOGENETIC SUBDIVISIONS OF CEREBELLUM



Cerebellar nuclei. There are four pairs of nuclei—**nucleus fastigii, nucleus globosus, nucleus emboliformis,** and **nucleus dentatus** (Fig. 5.160). Commonly fibres from the dentate, globose, and emboliform nuclei pass to the red nucleus, and fibres from the dentate and fastigial nuclei go to the reticular formation.

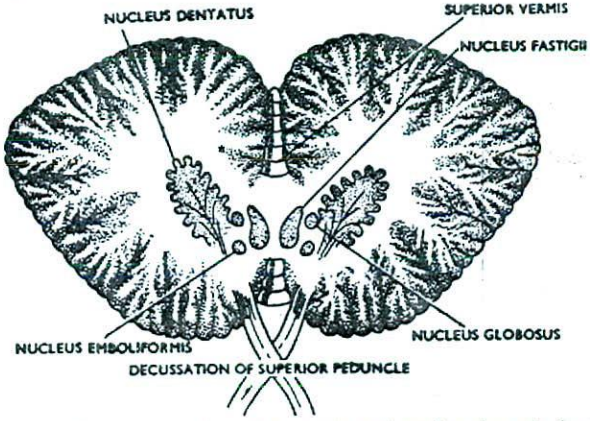


Fig. 5.160. Diagrammatic representation of the horizontal section through the cerebellum showing the cerebellar nuclei. (*modified after Best & Taylor*).

Histology (Fig. 5.161). The gray matter of the cerebellar cortex is thrown into folds and shows the following three distinct layers from inside outwards.

1. **Granular layer** (Inner layer). It contains (*a*) *small granular cells.* (*b*) Golgi cells (type II). The granular cells have multiple short dendrites and one long axon. The latter ascends to the molecular layer, bifurcates into the transverse branches parallel to the surface and communicates with many cells.

2. **Intermediate layer of Purkinje cells** (Middle layer). These cells are the *characteristic feature of cerebellum.* They have large flask-shaped bodies with freely branching dendrites extending into the molecular layer and one axon passing down to the cerebellar nuclei.

3. **Molecular (plexiform) layer** (Outer layer) consists of (*a*) *small stellate cells,* and (*b*) *basket cells.* The latter send transverse fibres ending round the bodies of many Purkinje cells and receive impulses from granular cells.

The **afferent fibres** entering the cerebellum go mostly straight to the cortex and are of two types: (1) **Mossy fibres**—mostly spinocerebellar and olivocerebellar fibres—passing through inferior cerebellar peduncle and ending in the granular layer. (2) **Tendril or Climbing fibres**—go up and communicate with the dendrites and bodies of the Purkinje cells. Derive mostly from pontine and vestibular sources and pass through middle cerebellar peduncle. Afferent fibres carry kinaesthetic, vestibular and cortical impulses (*via* pontine nuclei).

Efferent fibres leave cerebellum in two stages: (*a*) from the cortex to the deep nuclei; (*b*) from the deep nuclei to extracerebellar regions. Efferent fibres communicate with the motor centres at all levels of the central nervous system.

The **white matter** of the cerebellum lies deep in the gray matter and forms a white cove. It is composed of three sets of fibres such as:

1. **Projection fibres** passing through the peduncles (superior, middle and inferior) make connections with the extracerebellar region (Fig. 5.162).

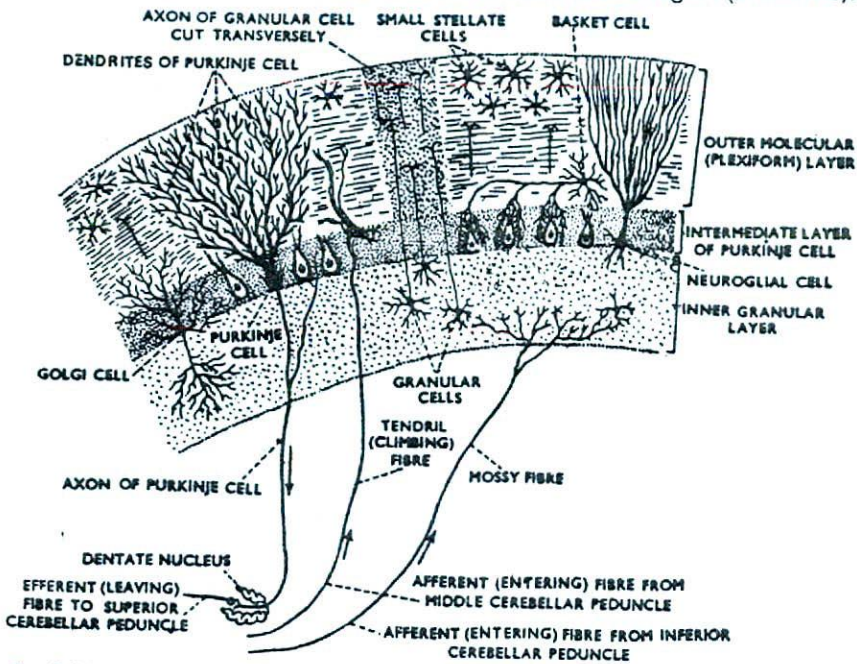


Fig. 5 161. Diagrammatic representation of cross-section of a folium of the cerebellum showing cellular connections. The Purkinje cells form a single stratum of large, flask-shaped cells at the junction of the molecular layer with the granular layer. Granular cells synapse with dendritic processes of the Purkinje cells of which axons enter the white matter and end in the cerebellar nuclei. The Golgi cells lie at the junction of the molecular and granular layers, and their dendrites pass into the molecular layer and form axodendritic synapses with the axons of granular cells. The tendril fibres wrap around the dendrites of the Purkinje cells. The basket cells receive impulses from the granular cells.

2. **Association fibres** connect different regions of the same hemisphere.

3. **Commissural fibres** connect cortical areas of the cerebellar hemisphere with the other.

Connections

The **afferent** (*entering*) and **efferent** (*leaving*) **fibres** connecting the cerebellum with the extracerebellar regions run through three large bundles which are known as superior, middle and inferior cerebellar peduncles (Figs. 5.163, 164 & 165).

Inferior Cerebellar Peduncle (Restiform Body)

Fibres passing through this peduncle are predominantly afferent and carry non-sensory impulses from labyrinth, joints, voluntary muscles, skin, etc.

Afferents

1. **Dorsal spinocerebellar tract.** The fibres of the tract from Clarke's column end in the anterior lobe, middle lobe of both sides, but mainly of the same side. The fibres also end in the nodule.

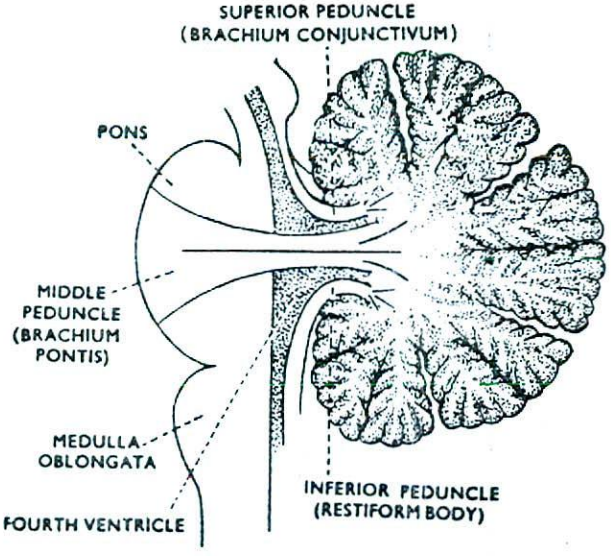


FIG. 5.162. Diagrammatic representation of the cerebellar peduncles (*after Best & Taylor*).

2. **External arcuate fibres.** Originating from the nucleus gracilis and nucleus cuneatus of the same side (*dorsal*) and also from opposite end in the paramedian lobule of the middle lobe and lobulus simplex of the anterior lobe.

3. **Vestibulocerebellar tract.** Originating from the vestibular nucleus of the same side and also directly from the vestibular nerve, it passes to the three cerebellar nuclei: *nucleus globosus*, *nucleus emboliformis* and mainly to *nucleus fastigii* and is relayed to the cortex of the flocculonodular lobe and of the uvula.

4. **Olivocerebellar tract.** Originating from the olivary nucleus of the same side as well as from opposite side it ends in the cortex of the middle lobe.

5. **Fibres of the fifth cranial nerve and also of ninth and tenth cranial nerves.** They end in the pyramid, uvula and paraflocculus.

6. **Tectocerebellar tract.** It originates in the midbrain colliculi and ends in the cerebellum. Its course is not clearly known.

Efferents

1. **Fastigiovestibular tract and fastigiobulbar tract.** Originating from the flocculonodular lobe and roof nucleus (nucleus fastigii) they end in the vestibular nuclei and medullary reticular formation. From the medulla, fibres descend in the spinal cord as vestibulospinal tract or reticulospinal tract.

2. **Cerebello-olivary tract.** Originating from the cerebellum it ends in the olivary nuclei of both sides.

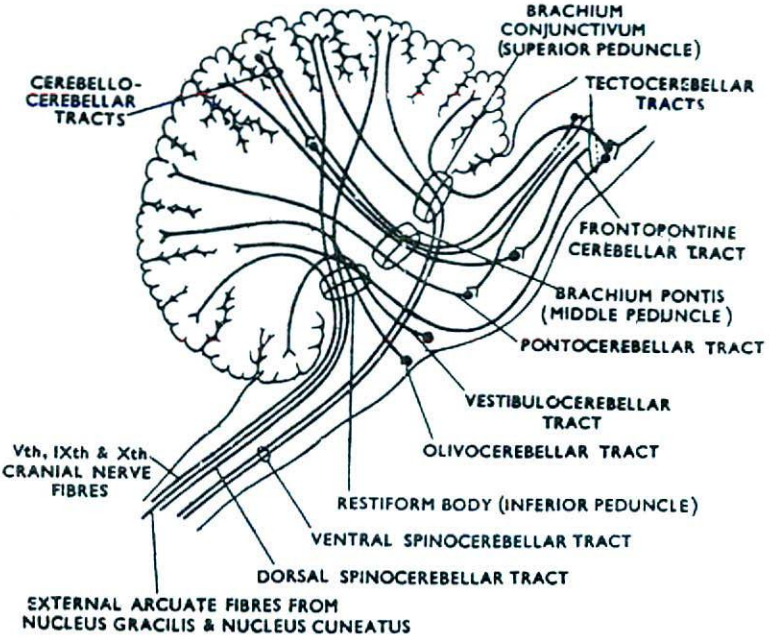


FIG. 5.163. Schematic representation of main afferent tracts to the cerebellum.

MIDDLE CEREBELLAR PEDUNCLE (BRACHIUM PONTIS)

Afferents

1. **Pontocerebellar tract.** Arising from the pontine nucleus, it ends in the middle lobe of the opposite side and a few fibres end in the homolateral hemispheres and vermis. This tract also constitutes the secondary neurones of the **frontopontocerebellar tract.**
2. **Fibres from cerebellum to cerebellum.** Fibres from the dentate nucleus of one side end in the cerebellar hemisphere of the opposite side.

SUPERIOR CEREBELLAR PEDUNCLE (BRACHIUM CONJUNCTIVUM)

Efferents

Fibres arising from the dentate nucleus and a few from the other nuclei decussate in the midbrain with the fibres of the opposite side and run as descending and ascending fibres. The ascending fibres comprise the (*i*) dentatothalamocortical tract, and (*ii*) dentatorubrothalamic tract.

1. **Dentatothalamocortical tract.** This tract ends directly into the lateral nucleus of the thalamus and is relayed to the cerebral cortex at areas 4 and 6.
2. **Dentatorubrothalamic tract.** Originating from the dentate nucleus this tract crosses in the region of the midbrain and ends in the

nucleus parvocellularis or nucleus magnocellularis of the red nucleus. Impulses from the parvocellularis of the red nucleus reach the cerebral cortex (areas 4 and 6) *via* rubrothalamic tract.

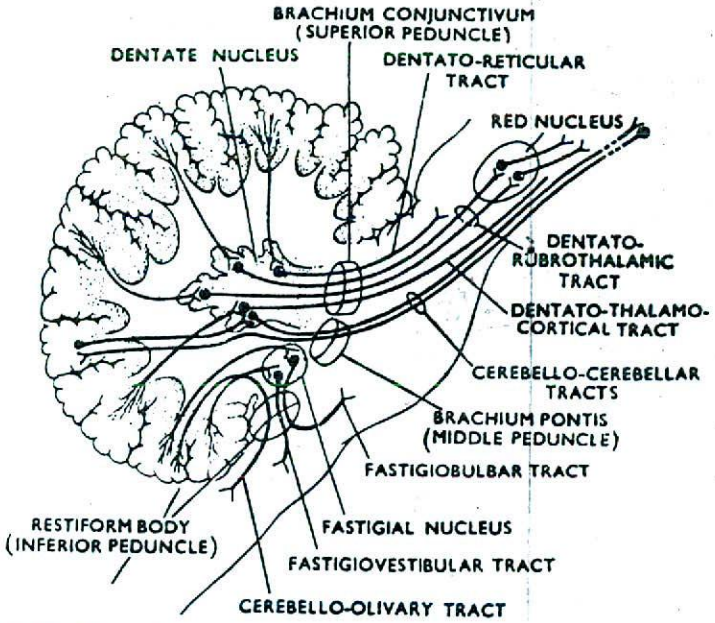


FIG. 5.164. Schematic representation of main efferent tracts from the cerebellum.

Descending tract comprises the fibres which end in the reticular formation of the pons, medulla oblongata and cervical spinal cord.

Afferents

1. **Ventral spinocerebellar tract.** Originating from Clarke's column this ascends through the spinal cord, medulla oblongata and pons, and ultimately ends in the cerebellum.
2. **Tectocerebellar tract.** Originating from the superior colliculus it ends in the cerebellum.

Considering the above connections with the extracerebellar nuclei, it may be argued that the cerebellum has got **cerebro-cerebello-cerebral connections.** Because the cerebellum makes connection with the cerebral cortex (areas 4 and 6) through the dentato-rubro-thalamo-cortical tract and the cerebral cortex (areas 4 and 6) in turn makes connection with the cerebellum through the frontopontocerebellar tract.

Steady voluntary movement initiated by the precentral motor cortex is maintained by this pathway.

Methods of study. Following methods are adopted:

1. Observing the effects of extirpation.
2. Observing the effects of stimulation.
3. Clinical study of disease, tumour, injury, etc., of cerebellum.
4. Noting the afferent and efferent connections of cerebellum.

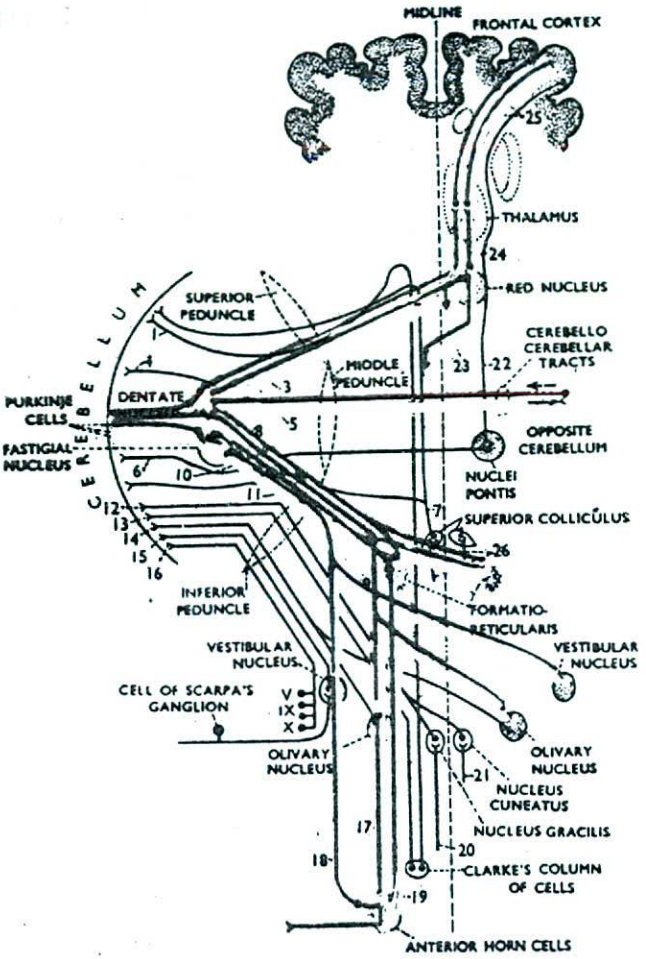


Fig. 5.165. Schematic representation of principal connections of the cerebellum. *Red* = efferent; *Black* = afferent.

1 = Ventral spinocerebellar tract (Gowers' tract). 2 = Dentatothalamic tract through red nucleus to thalamus. 3 = Dentatorubral tract—one branch passing down to end in various nuclei. 4 & 5 = Cerebello-cerebellar tracts [4 = from opposite cerebellum and 5 = to opposite cerebellum]. 6 = Pontocerebellar tract from nuclei pontis of opposite side. 7 = Tectocerebellar tract from superior colliculus. 8 = Dentatoreticular tract of both sides. 9 = Cerebello-olivary tract to olivary nucleus of both sides. 10 = Fastigiobulbar tract to formatio-reticularis of both sides. 11 = Fastigiovestibular tract to vestibular nucleus of both sides. 12 = External arcuate fibres from nucleus gracilis and nucleus cuneatus. 13 = Dorsal spinocerebellar tract (Flechsig's tract) from Clarke's column of cells. 14 = Olivocerebellar tract from olivary nucleus of both sides. 15 = Vestibulocerebellar tract from vestibular nucleus of same side. 16 = Fibres from V, IX and X cranial nerves. 17 = Olivospinal tract. 18 = Vestibulospinal tract. 19 = Reticulospinal tract. 20 = Tract of Goll. 21 = Tract of Burdach. 22 = Frontopontine tract. 23 = Rubrospinal tract. 24 = Rubrothalamic tract. 25 = Thalamocortical tracts. 26 = Spinotectal tracts.

5. Studying the histological details of cerebellum.

6. Comparative physiology, viz., evolution of cerebellum from the phylogenetic standpoint.

7. Electrical study. Exploration of the cerebellar cortex with microelectrodes and noting the arrival of nerve impulse after stimulation (or passive movements) of different regions of the body. It is seen that the proprioceptive regions of one-half of the body are represented *upside down* (same as in cerebrum) on the same half of the cerebellum (contrast with cerebrum).

Functions of cerebellum

From these studies two things become clear: (1) Control of cerebellum is ipsilateral, and (2) cerebellum is not concerned with conscious sensations. Functions of cerebellum may be summarised as follows:

Palaeocerebellum

It acts as a receptive organ for tactile, proprioceptive, auditory and visual impulses.

After stimulation of the tactile and proprioceptive receptors in the monkey, electrical changes have been recorded in the **anterior lobe** of the cerebellum. *Electrical changes* are produced on the *lobulus simplex* after stimulation of the *face* and *head*, on the *culmen* after stimulation of the *forelimb*, on the central lobule after stimulation of the *hindlimb*, and on the *lingula* after stimulation of the *tail* (Fig. 5.166).

Stimulation of the cerebellar cortex or nuclei increases flexor tone and inhibits extensor tone on the same side of the body. In the decerebrate animal, stimulation of palaeocerebellum inhibits the extensor rigidity on the same side (sometimes on both sides). Stimulation of the central lobule, culmen and lobulus simplex produces effects on hindlimbs, forelimbs, and head and face respectively.

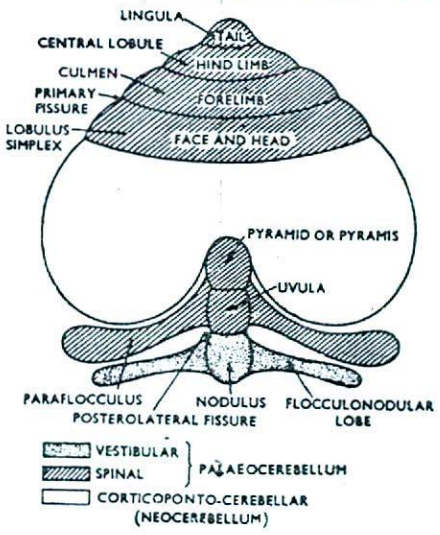


Fig. 5.166. Localisation of functions of cerebellum—Electrophysiological study.

After stimulation of the motor area of the cerebral cortex electrical changes are recorded in the contralateral areas of the cerebellum. So from these studies it may be concluded that *each half of the cerebellum controls the tone of the muscles on the same side of the body.*

Luciani demonstrated three stages **after extirpation of cerebellum** in dogs. (1) **First stage** (Functional exaltation)—Animal becomes restless showing increased extensor tone, opisthotonos, head retraction, etc. (2) **Second stage** (Maximal cerebellar deficiency)—(*a*) *Asthenia* (weakness), (*b*) *Hypotonia* (lack of tone), (*c*) *Ataxia* (inco-ordinated movement).

(3) **Third stage** (Compensation)—Defects are partially remedied by the development of better voluntary control. The animal walks carefully with legs wide apart thus obtaining a broader base to maintain equilibrium.

Later investigators found that if the vestibular nuclei are not injured asthenia and hypotonia do not occur in the decerebrate dogs. In decerebrate dogs the postural reflexes are exaggerated. The decerebrate monkeys behave otherwise. There is at first extensor spasms but not so marked as in dogs. Ataxia is also not severe and the animal is able to walk before complete recovery. Intention tremor is present. Postural reflexes are not exaggerated.

Extirpation of the flocculonodular lobe causes oscillation of the head, disturbance in maintaining the posture and equilibrium.

In lower mammals **anterior lobe** helps in the maintenance of muscle tone and synergic movements which are necessary for regulation of posture. The **middle lobe** which is highly developed in primates receives the corticopontine fibres and helps in co-ordinated and integrated movements of muscles.

Archicerebellum

The **flocculonodular lobe** being connected with vestibular apparatus through vestibular nerves helps in regulation of posture and equilibrium, but together with *lingula*, the flocculonodular lobe has spinocerebellar connections in addition to vestibular connections. In animals it seems to increase the flexor tone and to depress the extensor tone. But in man, it can adjust the tone of both protagonists and antagonists and thus exerts a perfect synergic control on antagonistic muscles.

Neocerebellum

It receives fibres from the nuclei pontis. Each cerebellar hemisphere receives fibres from the opposite side. The nuclei pontis receives fibres from the frontal and temporal lobes of the cerebral cortex. Some fibres are also received from the pyramidal tract. Through this path the cerebellum receives impulses from the cerebral cortex and is influenced by it. Again, from the dentate nucleus of the cerebellum some fibres are projected to the red nucleus and same to the thalamus and then are relayed to the cerebral cortex—*dentato-rubro-thalamo-cortical fibres*.

By its connections with cerebral cortex, it guides and controls all voluntary movements, so that they may be accurate in time, force, direction and extent. The neocerebellum also receives some tactile and proprioceptive impulses through the spinal cord.

Main functions of the cerebellum is the control of movement. Lesions of the cerebellum cause (*i*) disturbance in posture and postural tone, and (*ii*) disturbances in voluntary movement and fails to pick up any substance due to miscalculation of the distance and of speed of movement of the limb. Flocculonodular lobe is concerned with standing; and lesions in this lobe disturb in standing posture. Total cerebellectomy causes disturbances in tone of the muscle. Decerebrate rigidity is a release phenomenon and the γ-motoneurone activity is increased with an exaggerated extensor tone. The anterior lobe of the cerebellum is concerned with the γ-motoneurone activity. With the *ablation of the anterior lobe* in decerebrate animal, the γ-motoneurone activity is decreased but the α-motoneurone activity is increased due to vestibulospinal activity which is no longer inhibited by the cerebellum.

The cerebellum controls the actions of motor cortex through a **feedback mechanism.** It is concerned with smooth pattern of movement and regulation of the precision of the movement.

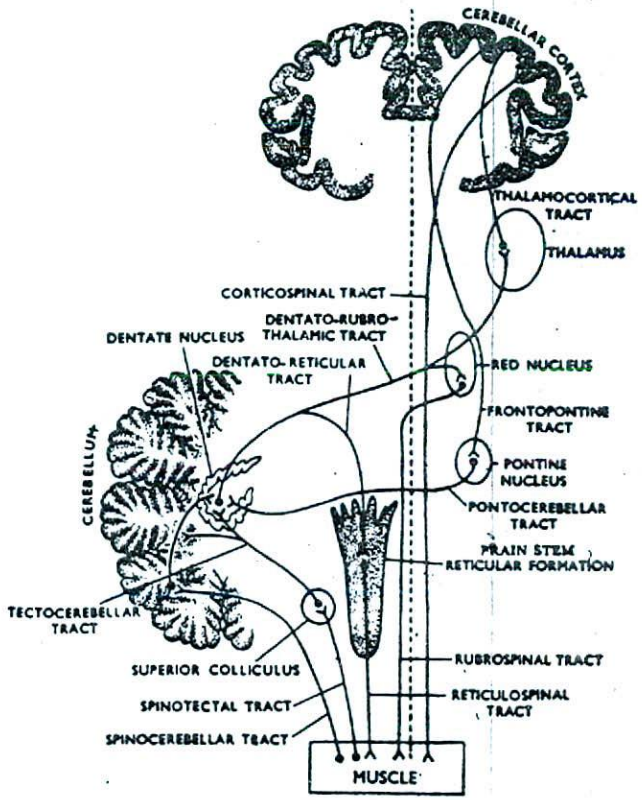


FIG. 5.167. Schematic representation of the cerebellar feedback system.

The diagram describes the pathways of feedback mechanism controlling the activity of the motor cortex (FIG. 5.167). During voluntary movements the motor cortex transmits motor impulses to the spinal cord motoneurone through the corticospinal tract. Collateral impulses are also transmitted to the cerebellum simultaneously through the frontopontocerebellar pathways. Thus during motor movements, the spinal cord motoneurone as well as the cerebellum get the motor impulses simultaneously. The cerebellum also receives the afferent impulses from the muscle spindle, tendons, etc., through the spinocerebellar tract and then sends impulses to the dentate nucleus and thence to the cerebral cortex back through dentato-rubro-thalamo-cortical pathways.

The degrees and extent of the movement for performing a particular work is being determined by the **feedback** or **error-controlling activity of the cerebellum.** The cerebral motor cortex generally sends impulses for more than it is actually required for performing a work and

the cerebellum then automatically inhibits the cerebral cortex after calculating the appropriate time and rate of movement required to reach the point of intention.

Summary

In general, the cerebellum is not involved with sensation or consciousness, because its removal does not cause any impairment of them. But it plays a very important role in the reflex regulation, posture and modulation or co-ordination of reflexes involved in motor acts. It acts as a *feedback centre* in between the cerebral cortex and peripheral motor movements and interruption of such feedback pathway may lead to oscillatory movement, i.e., what *the cerebral cortex initiates, the cerebellum regulates them.*

Archicerebellum. The flocculonodular lobe being connected with the vestibular nuclei plays an important role in regulation of posture and equilibrium.

Although the flocculonodular lobe is exclusively vestibular in its connections, but together with *lingula* it is *spinocerebellar* in addition to vestibular connections.

Palaeocerebellum. It is spinocerebellar in its connections predominantly. The anterior lobe helps in the maintenance of muscle tone and synergic movements, necessary for the regulation of posture—specially in mammals but in human beings and in other primates it does not play much significant role.

(*b*) Uvula and pyramid (pyramis) probably help in the regulation of equilibrium.

Neocerebellum. It receives predominantly corticopontocerebellar fibres. Through these fibres, it helps in the integration and co-ordination of muscular movements.

Although the **archicerebellum,** the **palaeocerebellum** and the **neocerebellum** are **functionally different,** yet they work in close co-operation. The neocerebellum guides to organise accurate motor impulses for precise volitional movements, whereas, at the same time, the palaeocerebellum and archicerebellum adjust the postural mechanism and thus create a suitable background against which all volitional movements take place. The recent idea about cerebellar function is that it acts as a 'comparator of a servomechanism'. It is an organ which receives proprioceptive, tactile, visual and auditory impulses and is also connected with the activities of the corticospinal neurone. Through the cerebellocerebral pathway it exerts its controlling influence over the corticospinal neurone and regulates the motor activity.

Cerebellar lesions

Cerebellar lesions of one hemisphere or peduncles will cause dysfunction on the same side of the body. Lesions of the vermis will affect both sides. The signs and symptoms of cerebellar diseases are much more manifested following lesions in the cerebellum. The clinical manifestations of the disease can be described under two broad headings: (*a*) defects of posture, (*b*) defects of voluntary movement. They are as follows:

Defects of posture—(1) *Hypotonia*—muscle tone is lost and becomes flabby. (2) *Defective attitude*—face turned towards the opposite side. (3) *Post-pointing* and *vertigo*—defective arm deviates to the side of lesion when raised straight in front with eyes closed (Barany's pointing test).

Vertigo is the sensation when the surrounding environment is rotating. It is not due to cerebellar disease but of vestibular or labyrinthine disorders. (4) *Static tremor* may develop when head or limb is held steadily. (5) *Nystagmus* and *deviation of eyes*—jerky movement of eyeball—spetially when looking at the side of lesion. (6) *Deep reflexes*—weak and sluggish and knee jerk becomes pendular.

Defects of voluntary movement—(1) *Asthenia*—weakness of movement. (2) *Ataxia*—inco-ordinated movement. Three parts of ataxia: (*a*) *Decomposition of movements*—a complex movement is carried out in parts. (*b*) *Asynergia*—inco-ordination between the protagonists and antagonists. (*c*) *Dysmetria*—wrong judgement about the force and extent of movement. (3) *Gait*—reeling, legs wide apart, deviates to the same side. (4) *Speech*—scanning. (5) *Intentional tremor*—tremor during voluntary movement. (6) *Adiadochocinesis* (after Babinski)—inability of the patients to execute pronation and supination of the forearm rapidly, or extension and flexion of fingers.

THALAMUS

This is a large collection of nerve cells at the top of the midbrain forming the medial boundary of internal capsule and lateral boundary of third ventricle. The following **five main nuclear masses** have been found in the thalamus: (*i*) Medial nuclear mass, (*ii*) Lateral nuclear mass, (*iii*) Midline nuclei, (*iv*) Intralaminar nuclei, (*v*) Pulvinar nuclei.

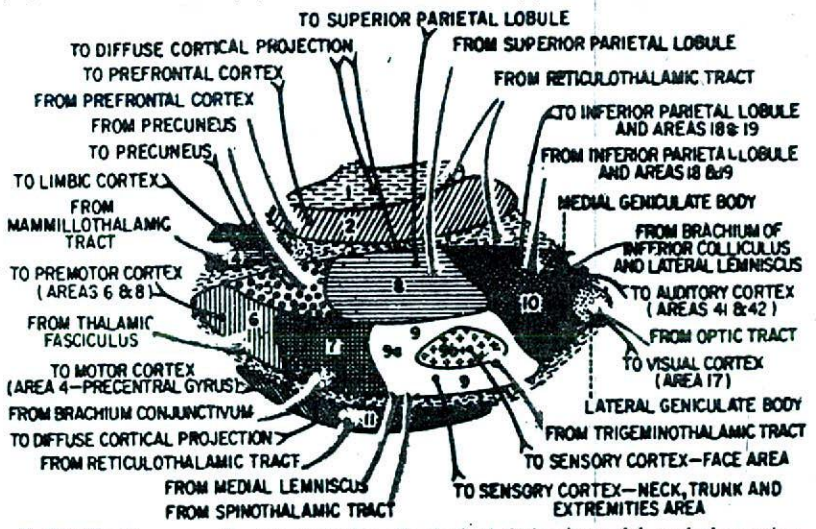


FIG. 5.168. Diagrammatic representation of principal thalamic nuclei, and also major *efferent* (black line) and *afferent* (red line) connections of thalamic nuclei. 1 = Midline nuclei. 2 = Medial dorsal nucleus. 3 = Intralaminar nuclei (Internal medullary lamina). 4 = Anterior nucleus. 5 = Lateral dorsal nucleus. 6 = Ventral anterior nucleus. 7 = Ventral lateral nucleus. 8 = Lateral posterior nucleus. 9 = Ventral posterior nuclei (9*a* = Ventral postero-lateral nucleus and 9*b* = Ventral postero-medial nucleus). 10 = Pulvinar nuclei. 11 = Reticular nucleus.

The *medial nuclear mass* and *lateral nuclear mass* are separated from each other by a vertical septum—the *internal medullary lamina*. In the *internal medullary lamina* there are also clusters of nerve cells, which are

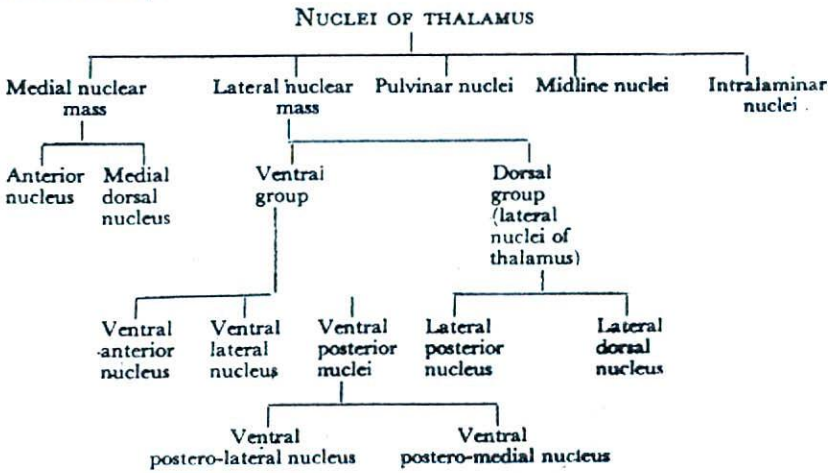
known as *intralaminar nuclei*. In the adjacent side of the medial nuclear mass there is a discrete group of nerve cells which are known as *midline nuclei*. At the posterior portion of the nuclei of lateral mass there is a large nuclear mass which is called as *pulvinar nuclei*.

The medial nuclear mass consists of two distinct cell groups: (*i*) anterior nucleus, and (*ii*) medial dorsal nucleus.

The lateral nuclear mass contains, like the medial nuclear mass, two distinct cell groups: (*i*) *dorsal group of the thalamus* (*lateral nuclei*), and (*ii*) *ventral group of the thalamus*. The ventral group of the thalamus are also composed of three portions: (*a*) *ventral anterior nucleus*, (*b*) *ventral lateral nucleus*, and (*c*) *ventral posterior nuclei*. The *ventral posterior nuclei* again contain two cell groups: (*a*) *ventral postero-lateral nucleus*, and (*b*) *ventral postero-medial nucleus*.

The *lateral nuclei of the thalamus* which are also described as dorsal group of nuclei are composed of *lateral dorsal nucleus* and *lateral posterior nucleus*.

The anatomical divisions of the thalamic nuclei have been presented schematically:



The *medial geniculate body* and *lateral geniculate body* are also included as a part of the thalamus. These two nuclei are known as **metathalamus.**

Connections (Fig. 5.168)

I. In the **medial nuclear mass:**

A. ANTERIOR NUCLEUS

Afferent: (*i*) Mammillary bodies—mammillothalamic tracts.

Efferent: (*i*) Paracentral lobules. (*ii*) Posterior part of cingular gyri.

B. MEDIAL DORSAL NUCLEUS

Afferent: (*i*) Prefrontal areas of cerebral cortex. (*ii*) Hypothalamus.

Efferent: (*i*) Hypothalamus. (*ii*) Corpus striatum. (*iii*) Prefrontal cortex.

II. In the **lateral nuclear mass:**

A. VENTRAL GROUP

(*a*) **Ventral anterior nucleus**

Afferent: (*i*) Globus pallidus *via* lenticular and thalamic fasciculi.

Efferent: (*i*) Different areas of corpus striatum, globus pallidus and also in part to anterior insular cortex (Angevine and Others, 1962).

(*b*) **Ventral lateral nucleus**

Afferent: (*i*) Globus pallidus. (*ii*) Dentate nucleus of the cerebellum of the opposite side *via* dentatothalamic tract. (*iii*) Ipsilateral red nucleus (rubrothalamic tract).

Efferent: (*i*) Preceptral areas of the cerebral cortex.(area 4).

(*c*) **Ventral posterior nuclei**

(1) VENTRAL POSTERO-MEDIAL NUCLEUS

Afferent: (*i*) Crossed fibres from the spinal and superior sensory trigeminal nuclei, ascending in association with the medial lemniscus. (*ii*) Uncrossed dorsal trigeminal tract.

Efferent: Postcentral gyrus.

(2) VENTRAL POSTERO-LATERAL NUCLEUS

Afferent: (*i*) Medial and spinal lemnisci.

Efferent: (*i*) Postcentral gyrus.

B. DORSAL GROUP (LATERAL NUCLEI OF THALAMUS)

(*a*) **Lateral dorsal nucleus**

Afferent: (*i*) Precentral cortex.

Efferent: (*i*) Precuneal cortex.

(*b*) **Lateral posterior nucleus**

Afferent: (*i*) Superior parietal lobule (areas 5 and 7).

Efferent: (*i*) Superior parietal lobule and a few fibres to postcentral and precentral regions of the cortex.

III. **Pulvinar nuclei:**

It has got internuclear connections with medial and lateral geniculate bodies (**metathalamus**) and also medial dorsal nucleus. It receives and sends fibres to supramarginal, angular convolutions, superior parietal lobule, occipital and posterior temporal cortex.

IV. **Midline nuclei** are found in the **massa intermedia:**

Afferent: (*i*) Corpus striatum and also from brain stem reticular formation.

Efferent: (*i*) Cerebral cortex. (*ii*) Red nucleus. (*iii*) Body of Luys (subthalamic nucleus). (*iv*) Midbrain nuclei. (*v*) Hypothalamus.

V. **Intralaminar nuclei:**

Afferent: (*i*) Medial and trigeminal lemnisci. (*ii*) Reticular formation of the brain stem—reticulothalamic tract.

Efferent: (*i*) Globus pallidus and also with neighbouring thalamic nuclei.

Metathalamic nuclei

MEDIAL GENICULATE BODY

Afferent: (*i*) Ascending auditory fibres originating from the trapezoid nuclei, superior olivary nuclei, lateral lemniscus and the inferior colliculus.

Efferent: (*i*) Auditory cortex and also fibres to nucleus of lateral lemniscus, trapezoid body, superior olivary nucleus.

LATERAL GENICULATE BODY

Afferent: (*i*) Lateral geniculate body is the end station of the optic tract.

Efferent: (*i*) Visual cortex and also send fibres to the calcarine cortex, superior colliculi and pretectal area.

Functions of the thalamus

Functions of the thalamus can be studied by several methods:

(*a*) By thalamic lesions and studying the symptoms developed by the experimental animal.

(*b*) By stimulation either by electrical or by pharmacological means.

(*c*) By studying alterations of different nervous functions in subjects having discrete thalamic lesions.

1. **Relay station.** It is the great relay station for pathways coming from cerebellum, cerebral cortex (postcentral gyrus) and projection from the peripheral sensory systems.

(*a*) **Cerebellar impulses.** Received by the ventral lateral nucleus and relayed to areas 4 and 6 of frontal lobe. Through this path cerebellum guides and controls cerebrum.

(*b*) **All sensations carried by the medial, spinal and trigeminal lemnisci.** Ventral posterior nuclei receive the medial, spinal and trigeminal lemnisci. Through these lemnisci, pain, temperature, touch and kinaesthetic sensations from the different parts of the body and from the face reach these nuclei. Except pain sensation all the impulses are relayed to the postcentral gyri (areas 3, 1, 2) of the cerebral cortex. Vestibular impulses are relayed to temporal lobe and taste sensations are relayed to the inferior part of postcentral gyri.

(*c*) **Olfactory sensations** received from the mammillary bodies are relayed to the hippocampal region.

2. **Centre for crude sensations.** Medial dorsal nuclei act as the primitive centres for crude sensations. Hence, they are collectively known as the **essential organ of thalamus.** In lower animals, where cerebrum is absent, thalamus acts as the highest sensory centre.

The sensory functions of the thalamus can be studied by cutting off its connections with cerebral cortex. By this procedure the thalamus becomes isolated from the cortex and its independent functions can be revealed. Such a preparation is called **thalamic animal.** The following features are seen (*thalamic syndrome*): (1) All epicritic sensibilities are lost but crude sensations remain, such as (*a*) light touch, tactile discrimination and localisation are lost, but crude touch, pressure, etc., can be felt. *Asterognosis and sensory ataxia* due to the loss of cutaneous and kinaesthetic sensations. (*b*) Any difference of temperature between 24°C. and 38°C. cannot be perceived (*vide* page 5-96). (*c*) Movements of limbs can only be recognised when of considerable amplitude. (2) Emotional aspects of sensations (*affective character*) are heightened. Relatively weak stimulus will arouse excessive feeling, such as a slight painful stimulus will cause excessive pain. Paroxysmal spontaneous pain occurs. (3) Thalamic lesions produce abnormal involuntary movements. Intention tremor and choreoathetosis are often observed in thalamic lesions.

3. **Reflex centre.** Thalamus is an important reflex centre. The emotional reactions, such as that of rage are mediated through thalamus.

4. **Arousal and Alerting reactions.** The ventral part of the thalamus includes the reticular nucleus and surrounds the dorsal thalamus. Afferent impulses from the reticular formation of the brain stem project to the intralaminar nuclei. The reticular nucleus receives impulses from the intralaminar nuclei. From the reticular nucleus efferent impulses are

projected to the cerebral cortex. The reticular nucleus plays a great role in the arousal and alerting reactions.

SUMMARY. Developmentally and topographically the thalamus may be divided into the following parts: (*a*) the **epithalamus** which has connections to the olfactory system, (*b*) the **ventral thalamus** whose functions and projections are debatable, and (*c*) the **dorsal thalamus** which is divided into nuclei. These nuclei project to all the parts of the neocortex diffusely and to the specific discrete regions of the neocortex and limbic system.

Midline and intralaminar nuclei of the dorsal thalamus, which project the whole neocortex, are collectively termed as **non-specific projection nuclei** which receive input from the reticular activating system, and which form relay stations of impulses responsible for the diffuse secondary response and alerting effect of reticular activation.

According to the projections to the specific areas the nuclei of the dorsal thalamus may also be divided into the following groups: (1) **Specific sensory relay nuclei** are formed by (*i*) medial and lateral geniculate bodies, and (*ii*) the ventrobasal group of thalamic nuclei. The former relay visual and auditory impulses to the visual and auditory areas of the cerebral cortex and the latter relay the somatesthetic information to the postcentral gyrus. (2) Nuclei concerned with motor function and anterior nuclei are collectively called **nuclei concerned with efferent control mechanism.** The motor group of nuclei receive input from the basal ganglia and cerebellum and project to the motor areas of the cerebral cortex. And the anterior nuclei receive afferent fibres from the mammillary bodies and project to the limbic cortex which is concerned with recent memory and emotion. (3) The third group of the dorsal thalamic nuclei are **concerned with complex integrative functions** formed by dorsolateral nuclei which project to the association areas of the cerebral cortex and are concerned with language, etc.

The **ventral thalamus** includes commonly the reticular complex or reticular nucleus which surrounds the dorsal thalamus on its anterior and lateral sides. This nucleus lie between the external medullary lamina and internal capsule. The intralaminar nuclei project fibres to all parts of the reticular nuclei, and almost all parts of the neocortex receive fibres from the reticular nucleus. The nucleus shows reticular appearance because heavily myelinated fibres of the thalamic radiations split the curved ribbon-like reticulonuclear cells into clusters. The thalamic entity can alone exert a widespread influence on the cerebrum. According to Rose (1952) the reticular complex only duplicates the projections of the dorsal thalamic nuclei.

The number of the reticular nuclear cells is small compared with the cortical cell population. The reticular nucleus receives fibres from all the intralaminar nuclei which in turn are the synaptic sites of afferent fibres from the ascending reticular formation. The tectothalamic and reticulothalamic tracts carry impulses which are aroused in the brain stem reticular formation by the sensory collaterals from the large ascending sensory pathways.

Those impulses are relayed from the brain stem reticular core through the intralaminar nuclei and the reticular nucleus of the thalamus to the cerebral cortex, are called 'non-specific' because the reticulothalamic

tract exerts effects on the electrical activity of broad areas of the cortex. The electroencephalographic studies can only reveal this influence of the intrinsic and the reticular nuclei on the activities of the cerebral cortex.

Mammillary bodies. These two small, round nuclear masses lie below the floor of the III ventricle and behind the optic chiasma. These nuclear masses receive fibres from ascending pathways and the olfactory areas of the brain. They also send fibres to the thalamic and other brain nuclei. They constitute relay stations for olfactory fibres and are concerned with olfactory reflexes.

INTERNAL CAPSULE

It is a V-shaped band of fibres, bounded medially by thalamus and caudate nucleus and laterally by the lentiform nucleus. The apex of V looks inwards. Most of the ascending and descending cortical fibres pass through this area. Since a large number of fibres remain condensed in this small area, slight damage (haemorrhage, etc.) to this region causes extensive loss of function on the opposite side. It is divided into three segments: (*a*) **Anterior limb**—between caudate and lentiform nuclei, (*b*) **Posterior limb**—between thalamus and lentiform nucleus, (*c*) **Genu**—the bend. The fibres passing through it are enumerated below, **from before backwards** (FIG. 5.169).

I. ANTERIOR LIMB	II. GENU AND ANTERIOR two-thirds OF POSTERIOR LIMB	III. POSTERIOR one-third OF POSTERIOR LIMB
1. **Thalamofrontal fibres.**	1. **Pyramidal fibres**	1. **Thalamic radiation.**
2. **Frontothalamic fibres.**	(*a*) **Corticobulbar (Corticonuclear) fibres.**	2. **Optic radiation.**
3. **Frontopontine fibres.**	(*b*) **Corticospinal fibres.**	3. **Auditory radiation.**
4. **Corticostriate fibres.**	2. **Corticorubral fibres.***	4. **Temporopontine fibres.**

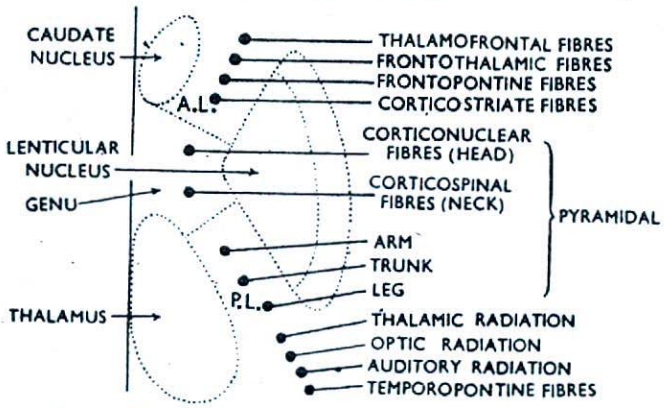


FIG. 5.169. Schematic representation of internal capsule showing the arrangement of ascending and descending fibres in it. A. L. = Anterior limb. P. L. = Posterior limb.

Lateral striate branch of the middle cerebral artery, recurrent branch of the anterior cerebral artery and anterior choroidal branch of the internal carotid artery supply the internal capsule. One of the branches of the

* Not shown in FIG. 5.169. It remains medial to the corticospinal fibres 1(*b*).

lateral striate artery or the lenticulostriate artery is frequently ruptured and it is known as **Charcot's artery of cerebral haemorrhage.** The rupture of this artery is due to the fact that the lenticulostriate artery remains under a very high pressure and it has no collateral branches. Haemorrhage due to the rupture of this artery causes 'apoplexy'. In apoplexy there is paralysis of the muscles of the opposite side of the body (hemiplegia), loss of consciousness, loss of control over the sphincters, etc. (*vide* page 5-128).

THE BASAL GANGLIA

The term **basal ganglia** is loosely used in the literature and not used by the modern neurologists. But considering its enormous uses and frequent acquaintance with the term in the literature, it has not been discarded yet. However, **corpus striatum** (*caudate nucleus, globus pallidus* and *putamen*), **claustrum, red nucleus, body of Luys** (subthalamic nucleus) and **substantia nigra** have been included in the basal ganglia (Figs. 5.170 & 5.171). But some authors have included the *corpus striatum*,

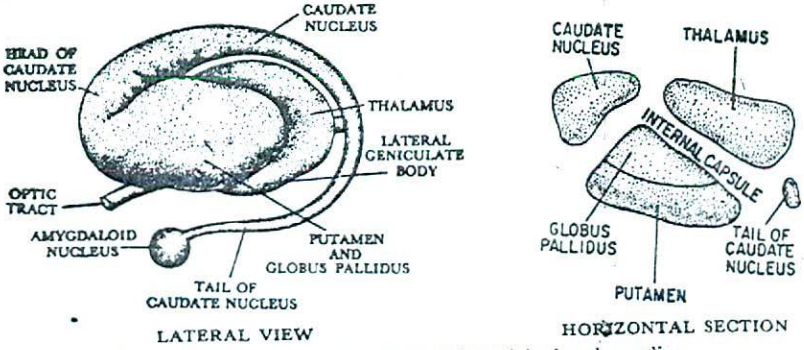


Fig. 5.170. Diagrammatic representation of the basal ganglia.

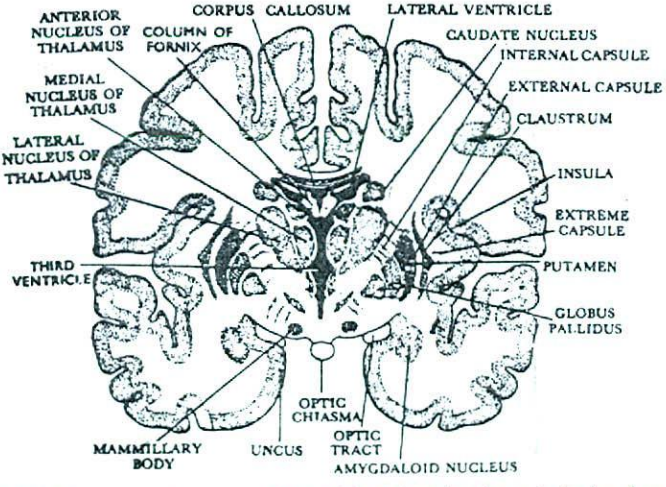


Fig. 5.171. Diagrammatic representation of *frontal* section through the basal ganglia.

amygdaloid nuclear complex and the *claustrum, substantia reticularis of the brain stem*, the *pontine nucleus*, the *inferior olive* and the *cerebellum*. The reticular formation is not only related to the muscular activity; but it has got other multiple functions. The pontine nuclei, cerebellum and inferior olive are far off from inclusion in the basal ganglia as the same have got other functions too. The amygdaloid nuclear complex has got no relation with the muscular movement and are included in the **limbic system.**

The basal ganglia plays an important part in controlling the voluntary, reflex and automatic associated movements of the body. Diseases of the different nuclear inclusions of the basal ganglia produce disturbances in muscular activities (muscular rigidity, tremor, athetosis, chorea, etc.).

Interconnections. The interconnections of basal nuclei (FIG.5.172). are complex. On each side, projections of the caudate nucleus in part to the putamen, the putamen to the globus pallidus, and the globus pallidus *via* the ansa lenticularis, efferent pathway from the lenticular nucleus, to the thalamus, body of Luys, red nuclei, etc. Feedback circuit projects from the motor cortex to the caudate nucleus and from the caudate nucleus back to the cortex *via* the lenticular nucleus, ansa lenticularis and thalamic ventrolateral nucleus.

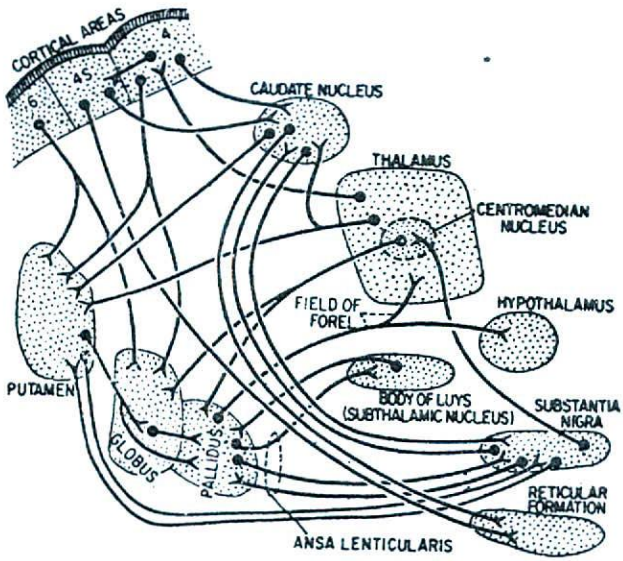


FIG. 5.172. Schematic diagram showing interconnections between basal ganglia, thalamus and cerebral cortex.

Metabolism. The basal ganglia use O_2 at a very rapid rate The metabolic rate of the cerebral cortex relative to that of the basal ganglia may be higher in man than in the dog. Oxygen consumptions of the adult dog's caudate nucleus and cerebral cortex are about 135 μl/100 mgm/hour and about 115 μl/100 mgm/hour respectively. The basal ganglia are sensitive to hypoxia in the human and the chronic hypoxia produces symptoms of Parkinson's disease and intellectual disorders. They also contain dopamine in a large amount. The substantia nigra and its adjacent locus caeruleus also

have high copper content. A familial disorder of ceruloplasmin (copper-binding protein) metabolism causes Wilson's disease and severe degeneration of the lentiform nucleus.

Corpus striatum

Anatomy. *Corpus striatum* is a mass of gray matter—lateral and anterior to thalamus. The anterior limb of internal capsule divides it incompletely into two parts: (1) The smaller anterior part is called the **caudate nucleus.** It lies medial to the anterior limb of the internal capsule. (2) The larger posterior part is known as the **lentiform (lenticular) nucleus,** lying lateral to the internal capsule. The lentiform nucleus is subdivided into a larger outer part—the *putamen* and a smaller inner part, the *globus pallidus* (pallidum).

Phylogenetically, globus pallidus is the primitive part (*palaeostriatum*), whereas putamen and caudate nucleus are more recent (*neostriatum*). On the outer side of the lentiform nucleus, there is a narrow band of white matter, called the **external capsule.** Still further out, there is an elongated island of gray matter, the **claustrum.**

Histology. Globus pallidus contains large pyramidal and multipolar cells (resembling Betz cells and anterior horn cells respectively). All efferent striatal fibres arise from it. Putamen and caudate nucleus contain small stellate cells, resembling sensory cortex and mostly receive afferent striatal fibres.

Connections of the corpus striatum (FIG. 5.173)

I. **Intrastriatal** (arising and ending within it):
(*a*) From putamen to globus pallidus.
(*b*) From caudate nucleus to putamen.
(*c*) From lateral to the medial part of the globus pallidus.

II. **Efferent** (Striofugal fibres). *All arise from globus pallidus* and end outside.
(*a*) **Striothalamic.** From globus pallidus to lateral nucleus of thalamus.
(*b*) **Striosubthalamic or Ansa lenticularis.** From globus pallidus to *red nucleus*, and other motor nuclei of the midbrain and hindbrain.
(*c*) **Striocortical.** A few fibres may go to cerebral cortex.

III. **Afferent** (Striopetal fibres). Arise elsewhere but end in corpus striatum:
(*a*) *Thalamostriate.* Thalamus to caudate nucleus and globus pallidus.
(*b*) From body of Luys to globus pallidus.
(*c*) From red nucleus to globus pallidus.
(*d*) Putamen and caudate nucleus receive fibres from the cerebral cortex (areas 4, 4S, 6, 8S and 2S). These fibres are relayed to globus pallidus from where the fibres are further projected into the reticular formation.

IV. **Commissural fibres.** From globus pallidus of one side to that of opposite side.

From the above it is clear that corpus striatum communicates directly or indirectly with: (1) cerebral cortex (areas 4, 4S, 6, 8S and 2S), (2) thalamus, (3) hypothalamus, (4) cerebellum, (5) midbrain, pons and spinal cord (through extrapyramidal tracts). In other words, it guides and controls the activities of almost all the important parts of nervous system, both somatic and autonomic. Caudate nucleus and putamen act as the

receiving centre, whereas globus pallidus acts as the discharging centre of basal ganglia.

Methods of study. (1) Histology, (2) connections, (3) comparative physiology, (4) extirpation, (5) stimulation, (6) striatal diseases, etc.

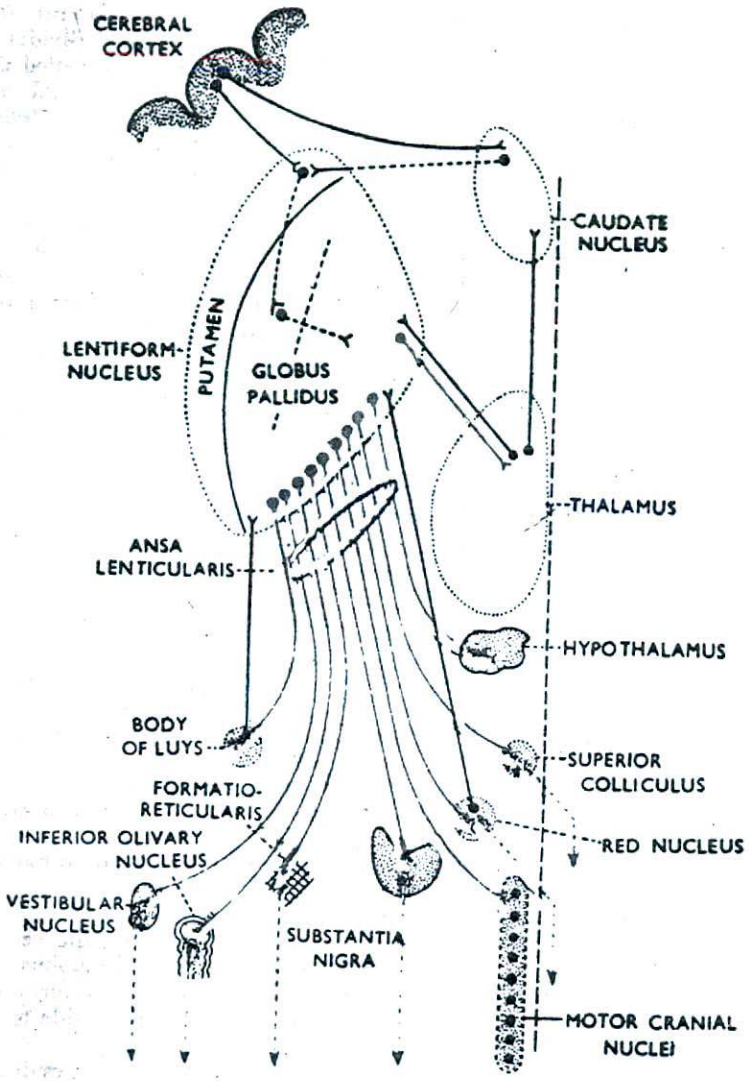


FIG. 5.173. Connections of corpus striatum.
Red = efferent; *Black* = afferent; *Red (dotted)* = intrastriatal.

Red nucleus

It is a large oval mass of gray matter in the tegmentum of midbrain

lying below the thalamus close to the third nerve nucleus. The colour of the **red nucleus** is due to the presence of a reddish-brown lipochrome (*vide* Volume 1). *Phylogenetically*, it consists of an old part with large cells (*nucleus magnocellularis*) and a new part with small cells (*nucleus parvocellularis*). From the old part, the motor fibres arise. While the new part receives all the afferent fibres.

Connections (FIG. 5.174)

I. **Efferent**

1. To globus pallidus—Rubrostriatal.
2. To lateral nucleus of thalamus—Rubrothalamic.
3. To inferior olivary nucleus—Rubro-olivary (not shown in the FIG. 5.174).
4. To formatio reticularis of pons and medulla.
5. To motor nuclei of cranial nerves—Rubrobulbar.
6. To spinal cord—Rubrospinal tract (*vide* page 5-130).

II. **Afferent**

1. From motor cortex (areas 4 and 6)—Cortico-rubral.
2. From globus pallidus of the same side—Pallido-rubral tract.
3. From vestibular nucleus of the same side—through posterior longitudinal bundle.
4. From cerebellum of opposite side—Arise from dentate nucleus of opposite cerebellar hemisphere, pass through superior cerebellar peduncle and enter the red nucleus. Some fibres actually end in it (**dentatorubral tract**). Others pass through it to the thalamus without having any synaptic connection in the red nucleus (**dentatorubrothalamic tract**). Probably the kinaesthetic impulses from spinal cord, carried through Flechsig's and Gowers' tracts are relayed to the red nucleus through these fibres.

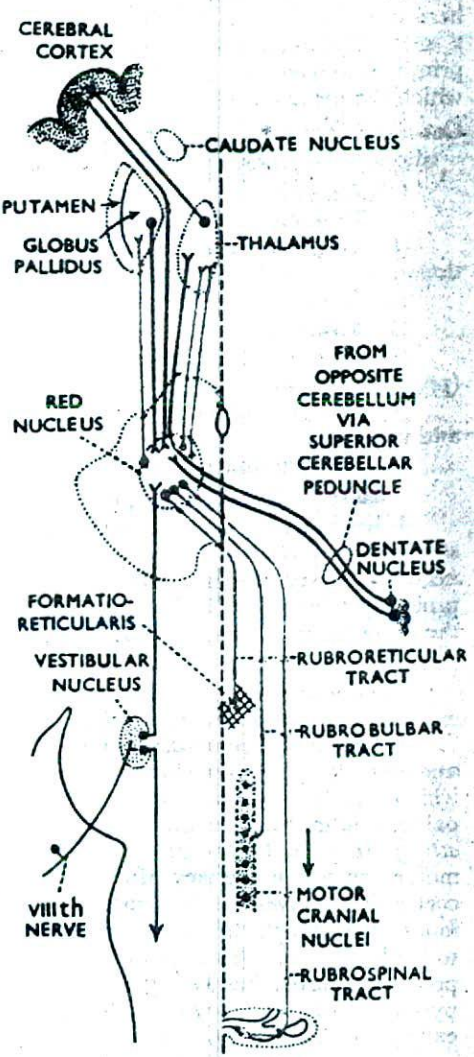


FIG. 5.174. Connections of red nucleus. *Red* = efferent; *Black* = afferent.

Substantia nigra

It is a crescentic mass of nerve cells containing melanin (hence blackish). It lies between the crus cerebri and tegmentum of midbrain. What function melanin serves here is not known. It may be a metabolic remnant of the primitive ectodermal cells from which the nerve cells are born.

Connections of substantia nigra (FIG. 5.175)

I. **Efferent**

(*a*) To globus pallidus.

(*b*) To globus pallidus *via* thalamus.

(*c*) To red nucleus.

II. **Afferent**

(*a*) From cerebral cortex (precentral gyrus).

(*b*) From caudate nucleus and putamen.

(*c*) From subthalamic nucleus (Whittier and Mettler, 1949).

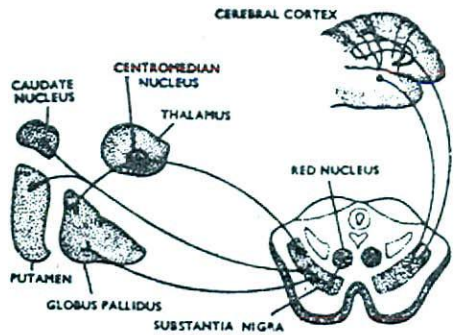


FIG 5.175. Schematic representation of some connections of substantia nigra with other parts of basal ganglia (subthalamic nuclear connection not shown).

Body of Luys or Corpus Luysi (Subthalamic nucleus)

It lies lateral and ventral to the red nucleus and dorsal to the substantia nigra. It is quite distinct from the hypothalamic nuclei. It is connected with red nucleus, substantia nigra, globus pallidus (*pallidum*) and probably others (FIG. 5.177). Functionally, it is believed to be a part of the extrapyramidal system (*vide* page 5-183).

Functions of the basal ganglia

Functions of the basal ganglia are still not clear but from the various experimental studies following functions can be stipulated:

1. **It is the primitive motor cortex for voluntary muscular activity.** In lower vertebrates (fishes, amphibia, reptiles and birds) in which cerebrum is rudimentary, corpus striatum (globus pallidus—palaeostriatum) acts as the highest motor centre for the *voluntary muscular activity*. In primates the precentral cortex (areas 4 and 6) is the highest motor centre. In monkey after removal of area 4 from the precentral cortex which gives rise to corticospinal fibres (keeping area 6 intact) it is found that though the movements become limited but the animal is able to walk, sit, etc. This may be due to combined action of area 6 of the precentral cortex, basal ganglia and other subcortical centres. In lesions of pyramidal tracts and area 6 of the precentral cortex, the basal ganglia and extrapyramidal tracts help in the voluntary movements.

2. **Controls reflex muscular activity.** Corpus striatum, precentral area of cerebral cortex, area 4S and the bulbar reticular formation by exerting inhibitory effect on the spinal reflexes regulate the activity of the muscles which maintains posture. Thus diseases of the basal ganglia produce muscular rigidity which is the characteristic disease such as *Parkinson's paralysis agitans*. Lesions in the globus pallidus and substantia nigra are concerned with the tremor in *Parkinsonism*.

3. **Controls automatic and associated movements.** These movements, normally initiated by area 6, are mediated through corpus striatum, such as swinging of arms during walking.

4. **Checks abnormal involuntary movements.** In lesions of the corpus striatum, abnormal involuntary movements occur.

5. **Controls the group movements for emotional expressions.** Subjects suffering from striatal diseases show lack of emotional expressions (Mask-like appearance).

6. **Red nucleus** is a relay station and a co-ordinating centre for many motor and sensory impulses and acts as a centre for righting reflexes.

7. **Substantia nigra** is highly developed in man and higher apes. It is regarded as the centre for the co-ordination of those impulses which are essential for the skilled movements.

Most of the above functions are still unconfirmed and imperfect also. However, the functions of the basal ganglia are connected in some ways with oscillatory functions of the motor systems probably through mediation of midbrain centres.

Clinical manifestations associated with the diseases of the basal ganglia

Diseases of the basal ganglia show the following clinical features such as: (1) *Muscular rigidity* causing disturbances in postural reflexes. (2) Abnormality in reflex muscular activity. (3) Disturbances in automatic and associated movements. Voluntary movements are impaired no doubt but no paralysis is observed in human beings.

The **clinical syndromes of diseases of the basal ganglia** are:

1. *Parkinsonism*—Paralysis agitans. 2. *Progressive hepatolenticular degeneration* or *Wilson's disease*. 3. *Chorea*. 4. *Athetosis*. 5. *Torsion spasm*. 6. *Hemiballismus* or *hemichorea*.

1. **Parkinsonism—Paralysis agitans.** The main features in this syndrome are: (*a*) *Coarse tremor in head and limbs*—The tremor becomes more pronounced during emotional excitement and disappeared during sleeping. Section of the lateral corticospinal tract may cause disappearance of the tremor. (*b*) *Muscular rigidity*—Affecting all muscles, specially the flexors causing a general attitude of flexion. The man sits like a statue. The characteristic features of rigidity of the muscles are different from those in decerebrate rigidity. Here stretch reflexes are normal. *Lead-pipe rigidity* is the feature during passive motion of an extremity with a plastic, dead-feeling resistance. Occasionally there is *cogwheel rigidity* which is a series of 'catches' during passive motion. (*c*) *Disturbances in movements*—Control of smooth co-ordinating movements is absent. All movements are weak, slow, irregular, and easily fatigued. The patients move in haste with short quick steps and having tendency of falling on the ground. If the patient is asked to check his movement (*propulsion* and *retropulsion*) cannot do so quickly and move a little forward. (*d*) *Absence of automatic and associated movements* are the striking features of the Parkinsonism. Swinging of the arms during walking is absent. The striking absence of associated movements is called *poverty of movement*.

All the features described above are not observed in each patient and are caused due to lesion in globus pallidus (*pallidum*) or substantia nigra.

2. **Progressive hepatolenticular degeneration or Wilson's disease.** This syndrome was first described by Wilson (1912) and accordingly it is known as Wilson's disease. This is caused by the cellular degeneration of the putamen and globus pallidus (*vide* p. 5-177). The caudate nucleus is not practically affected. The main features of this syndrome are: (*a*) *Muscular rigidity* where both the flexor and extensor muscles are affected. The rigidity is very widely spread and affects the muscles of face, trunk and limbs. The rigidity of the facial muscles always gives blank expression as the mouth is kept widely open. (*b*) *Increased tremor* like involuntary movements which are often exaggerated during excitement. (*c*) *Cirrhosis of the liver* is often encountered possibly due to disturbances in *copper metabolism.* (*d*) *Emotional disturbance* which involves involuntary laughing or crying. (*e*) Certain *greenish-brown pigmentation* is generally encountered in the cornea. (*f*) All *reflexes* generally remain unaffected.

3. **Chorea.** It is the disease caused by irregular and spasmodic movements beyond the patient's control and voluntary movements even become jerky.

It is mainly of two types of which one is the *childhood disease* caused by rheumatic fever and hence it is known as rheumatic chorea or St. Vitus's dance or Sydenham's chorea. Other one is *adult type* and is a rare familial disease and is transmitted as a dominant character to the off-spring. The main feature of this type of disease is the abnormal gesture and distortion of face during speaking. This disease is known as **Huntington's chorea.** It is due to disease of small cells of caudate nucleus and putamen.

4. **Athetosis.** It is the disease occurring often in the childhood associated with damage to the caudate nucleus and putamen during birth. It is a form of abnormal involuntary movements. In choreo-athetosis there are quicker and jerky involuntary movements. These abnormal movements are absent during sleep and predominant during waking.

5. **Torsion spasm.** It is a rare disease and consists of abnormal involuntary turning, twisting movements of trunk, neck and distortion of extremities of the body causing a *bizarre caricature.*

6. **Hemiballismus or Hemichorea.** It is the result of vascular lesions in subthalamic nucleus of Luys and often observed in older age groups having cerebral arteriosclerosis. Clinical features of this disease are flinging abnormal movements of the extremities on one side of the body. This abnormal movement can be abolished by dividing the corticospinal tract or by section of the anterior white column of the spinal cord.

SUBTHALAMUS

The subthalamus is bounded dorsally by the thalamus, medially and rostrally by the hypothalamus, and laterally and ventrally by the pes pedunculi and the neighbouring area of the internal capsule (FIG. 5.176). Actually it contains the rostral portions of the red nucleus and the substantia nigra. The main fibre bundles of the subthalamus are the tegmental area of Forel (Field H, prerubral field), the fasciculus lenticularis (Field H_2 of Forel), the fasciculus thalamicus (Field H_1 of Forel), and the ansa lenticularis (FIG. 5.177). The intrinsic gray masses comprises the subthalamic nucleus (corpus Luysi), the zona incerta, the subthalamic reticular nucleus (the nucleus of tegmental area H).

The **subthalamic nucleus** (body of Luys) is placed at the junction of the subthalamus and midbrain. It is an ovoid or lense-shaped gray mass of fairly large multipolar nerve cells.

The main **afferent fibres** of the subthalamic nucleus come from the lateral segment of the globus pallidus *via* the subthalamic fasciculus. Studies of human frontal lobotomy have revealed that some corticofugal fibres probably project to the subthalamic nucleus, but experimental studies do not reveal such. According to some, the subthalamic nucleus sends fibres to the substantia nigra and probably to the midbrain tegmentum.

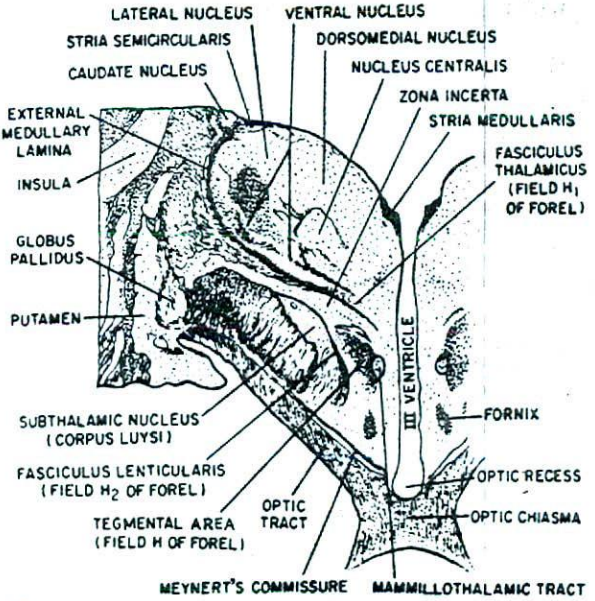


FIG. 5.176. Diagrammatic representation of a transverse section through the diencephalon and the basal ganglia at the level of optic chiasma.

The principal **efferent projection** from the subthalamic nucleus is to the globus pallidus.

Lesions in the subthalamic nucleus give rise to hemiballism. Violent involuntary movements occur contralateral to the lesion in the subthalamic nucleus and involve usually the proximal musculature of the upper and lower extremities though they may involve the facial and cervical musculature as well. The subthalamic nucleus normally exerts inhibitory and regulating influences upon the globus pallidus. A lesion in the subthalamic nucleus releases the globus pallidus from this controlling influence. Removal of this controlling influence is defined physiologically by bursts of irregular, forceful, large amplitude ballistic movements on the opposite side of the body.

The **fasciculus lenticularis** and the **ansa lenticularis** form the main efferent fibres from the globus pallidus. Many of the efferent fibres of the pallidum perforate the peduncular area of the internal capsule and constitute the lenticular fasciculus. This fasciculus runs medially near

the inner surface of the internal capsule and the subthalamic nucleus. Another group of efferent fibres from the inner segment of the globus pallidus sweep around the medial border of the internal capsule forming the ansa lenticularis which is a looped bundle. This bundle curves dorsally to join the lenticular fasciculus. A certain number of fibres from the ansa and the lenticular fasciculus terminate in the subthalamic nucleus and the nucleus of the tegmental field. Other fibres merely pass around the subthalamic nucleus to reach the thalamus, the hypothalamus and also other nuclear masses of the brain stem of Forel. The nucleus of the ansa lenticularis or entopeduncular nucleus is formed by strands of cells scattered along and between the fibre bundles of the ansa. These cells are believed to be detached cells of the globus pallidus due to their resemblance. They generally receive fibres from the putamen and caudate nucleus and contribute fibres to the ansa lenticularis.

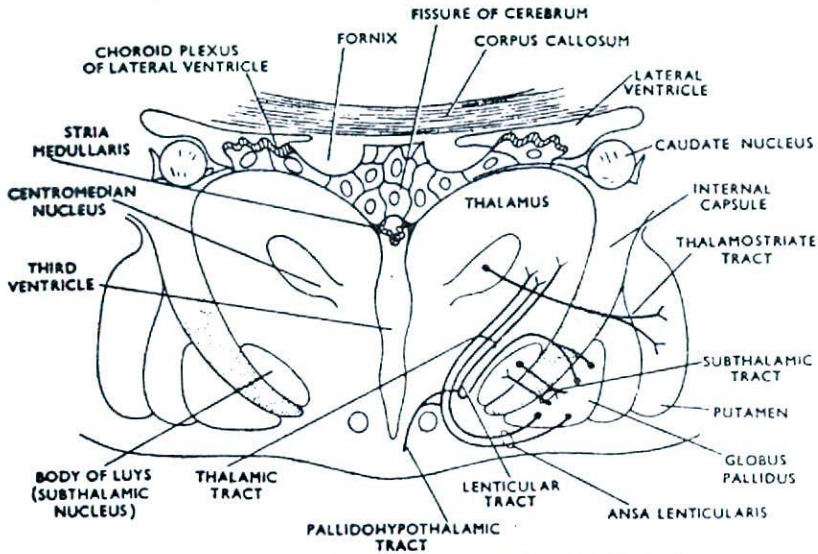


FIG. 5.177. Diagrammatic representation of the pallidofugal fibres.

The **fasciculus thalamicus** is closely applied to the ventral surface of the thalamus and possess several fibre bundles. Some fibres from the lenticular fasciculus loop laterally, enter the thalamic fasciculus and go to the ventral anterior nucleus of the thalamus. Other bundles are dentatothalamic and rubrothalamic fibres which pass through the tegmental area of Forel and thalamic fasciculus to the ventral lateral nucleus of the thalamus.

The **tegmental area of Forel** includes fibres and scattered cells which form the nucleus of the tegmental or **prerubral field.** Some bundles are dentatothalamic and rubrothalamic fibres which continue into the thalamic fasciculus to reach the ventral lateral nucleus of the thalamus. Other fibres from the lenticular fasciculus pass directly or collaterally into the prerubral nucleus. From the nucleus of the prerubral field the fibres may partly enter the rostral part of the red nucleus and the midbrain reticular formation.

lenticular fasciculus. Its diffuse cell groups receive fibres from the globus pallidus and the precentral cortex and is closely associated with the intralaminar thalamic nuclei, the red nucleus, and the midbrain tegmentum. The zona incerta and the **subthalamic reticular nucleus** possess a common origin and may be defined as the subthalamic continuation of the midbrain reticular formation.

Electrophysiological studies on monkeys and cats reveal that the gray masses of the subthalamus, including the subthalamic nucleus, are main functional components of the brain stem reticular system. Stimulation of the subthalamus increases muscle tone, facilitates reflex and cortically induced movements, and induces the electrical recruiting response over widespread cortical areas. Stimulation of the subthalamus, together with the neighbouring portion of the hypothalamus may produce similar responses.

THE RETICULAR FORMATION

Diffused ill-defined mass of nerve cells and fibres forming a meshwork or reticulum in the central portion of the brain stem is collectively known as *reticular formation*. It is extended downwards into the spinal cord and upward in the thalamus and subthalamus. Brain stem reticular system consists of the bulbar reticular formation, pontomesencephalic tegmentum, hypothalamus, subthalamus, and certain thalamic nuclei including the thalamic reticular nuclei. These include all cells and their connections excepting the cranial nerve nuclei relay nuclei of the cerebellar system and relay nuclei of the lemniscal systems.

In the tegmentum of the brain stem there is an extensive field of intermingled white matter and gray matter. These nuclear and fibre

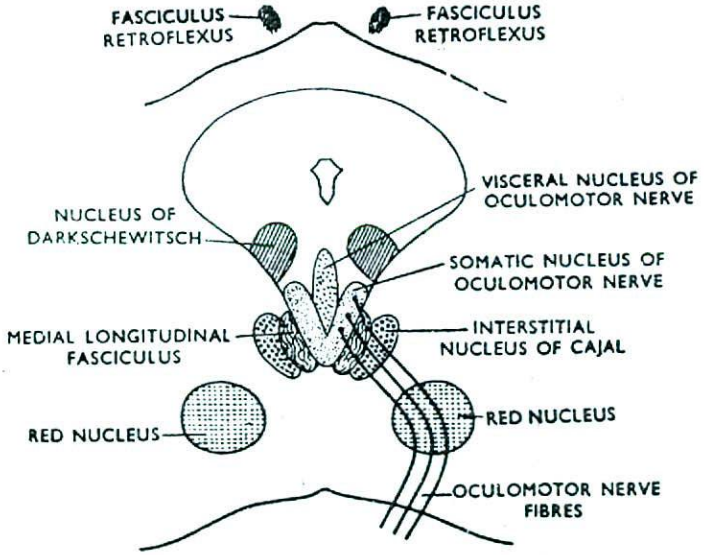


FIG. 5.178. Diagrammatic representation of the nuclei in the periaqueductal region showing the nucleus of Darkschewitsch lies within central gray dorsal to the medial longitudinal fasciculus.

bundles are collectively called the reticular formation. In the medulla oblongata there are two separate sets of nuclear masses—one is known as *lateral reticular nucleus* placed dorsolateral to the olivary nucleus and another is known as *inferior medial reticular nucleus* placed dorsal to the olivary nucleus. In the pons, there are *three* sets of nuclear masses of which (*i*) the central tegmental reticular nucleus of pons extends from medulla oblongata to the pons in central region, (*ii*) the caudal pontine reticular nucleus lies below the motor nucleus of the trigeminal nerves, and (*iii*) the oral pontine reticular nucleus above the motor nucleus of the trigeminal nerve extends cranially into the midbrain. In the midbrain the reticular mass includes red nucleus, the nucleus tegmenti pedunculopontinus, nucleus cuneiformis and nucleus subcuneiformis. These are the principal nuclei constituting the reticular formation. Besides these, certain tegmental nuclei—the interstitial nucleus of Cajal, the nucleus of Darkschewitsch (Fig.5.178), the nucleus of posterior commissure (Fig.5.179) and the dorsal

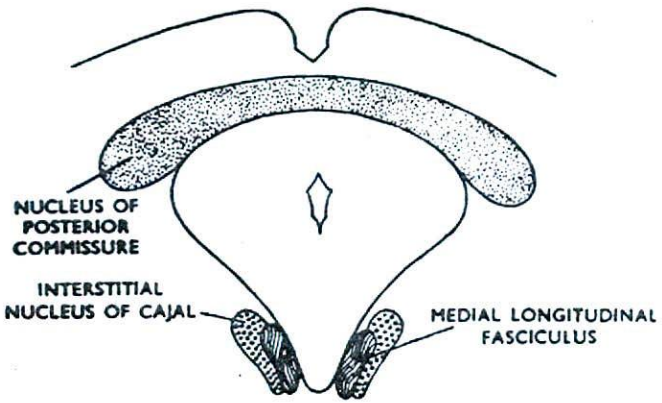


Fig. 5.179. Diagrammatic representation of the nucleus in the periaqueductal region showing the nucleus of the posterior commissure lies dorsal to central gray to the medial longitudinal fasciculus.

tegmental nucleus are included in conjunction with the reticular formation of the tegmentum.

The brain stem reticular formations are concerned with arousal phenomena, alertness, maintenance of attention and with sleep. It is also concerned with the muscle tone and posture, regulation of vegetative visceral and vasomotor responses, emotional expression, etc.

With the above physiological functions, the brain stem reticular formation comprises mainly two systems—**ascending reticular activating system** and **descending reticular system.**

THE ASCENDING RETICULAR ACTIVATING SYSTEM

The parts of the reticular formation which play roles in wakefulness and in controlling the overall degree of activity of the brain are called the *ascending reticular activating system.* The reticular activating system is a complex multineuronal and polysynaptic pathways; and collaterals from long ascending sensory tracts as well as from the trigeminal, auditory, visual and olfactory systems are projected into it.

The ascending reticular activating system begins in the lower brain stem and extends upward through the mesencephalon, thalamus and finally projected throughout the cerebral cortex (FIG. 5.180). Ascending reticular activating system of the brain stem sends impulses to the cerebral cortex *via* two pathways. One pathway originating from the mesencephalic reticular formation runs upwards to the subthalamus and is projected diffusely to the cerebral cortex. Another pathway originating from the mesencephalon runs upwards through intralaminar and midline nuclei of the thalamus to the ventral anterior nuclei and reticular nuclei of the thalamus and ultimately projects in all parts of the cerebral cortex.

Functions of the mesencephalic (midbrain) reticular activating system. The stimulation of the midbrain reticular activating system produces wakefulness by generalised activation of the entire brain including cerebral cortex, thalamus, basal ganglia, brain stem and spinal cord. Wakefulness is generalised and enhanced activities of the different

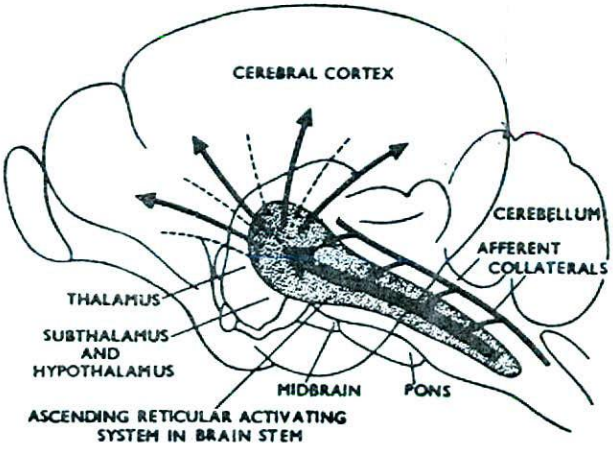


FIG. 5.180. Diagrammatic representation of ascending reticular activating system (*after Ganong*).

parts of the brain and sleep is the lack of adequate brain excitation. During sleep the reticular activating system is almost totally dormant. Any type of sensory impulses such as proprioceptive impulses from muscle, pain from skin, auditory, visual and even visceral, causes sudden activation of this reticular activating system producing arousal phenomena in the animals. *Epinephrine* also stimulates the midbrain reticular activating system producing generalised and increased activities of the brain. If the brain stem is dissected at higher level then the arousal phenomena are less effective but electrical stimulation of the reticular nuclei above the transection produces arousal activity.

Functions of the thalamic portion of the reticular activating system. This portion of the reticular activating system is different from that of the midbrain activating system. Projections from this nuclear mass end to a specific area of the cerebral cortex. Besides this, it relays some of

the mesencephalic (midbrain) facilitatory signals to the cerebrum in diffused mannet so as to cause a generalised activation.

Cerebral activation of the reticular activating system. In turn cerebral cortex also activates the reticular activating system by sending fibres from sensory motor cortex of precentral and postcentral gyri, the

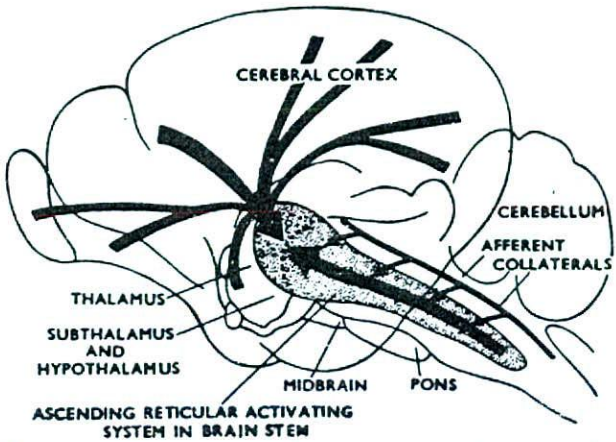


FIG. 5.181. Schematic representation of the convergence of pathways from the spinal afferent systems and from the cerebral cortex on the reticular activating system (*modified after Guyton*).

frontal cortex, cingulate gyrus, hippocampus and other structures of the rhinencephalon (FIG. 5.181). This activating system of the cerebrum is important as the motor activity of the body is highly associated with the wakefulness.

Feedback theory for the maintenance of activation of the reticular activating system (FIG. 5.182)

Once the reticular activating system is activated, it is maintained in a reverberatory fashion for some time. The ascending reticular activating system greatly intensifies the degree of activities of cerebral cortex and in turn cerebral cortex stimulates the reticular activating system.

This increased activity of the reticular activating system increases degree of muscle tone and also other peripheral activities. These peripheral activities may cause increased somatic impulses which are transmitted to central nervous system so as to produce the high degree of arousal activity. This shows that the activity of the reticular activating system produces increased peripheral activities which stimulate in turn the reticular activating system to evoke increased excitation. Furthermore, with the excitation of the reticular activating system, sympathetic system is stimulated with the liberation of *epinephrine* which stimulates in turn the mesencephalic portion of the reticular activating system. Sleep and wakefulness in an individual can be explained on the basis of the above feedback theories. Once the reticular activating system is excited it is maintained for some time by the feedback impulses originated from cerebral cortex and back, peripheral muscles and back and sympathetic activity and back through

liberation of epinephrine. After a prolonged wakefulness, the neuronal cells of the reticular activating system becomes inexcitable and the feedback mechanism gradually fails to keep the reverberatory process active —causing further depressions of the reticular activating system and sleep ensues. After a period of sleep the neuronal cells of the reticular activating system get back its excitability and if further activated by any arousal signal then wakefulness occurs with the onset of feedback process.

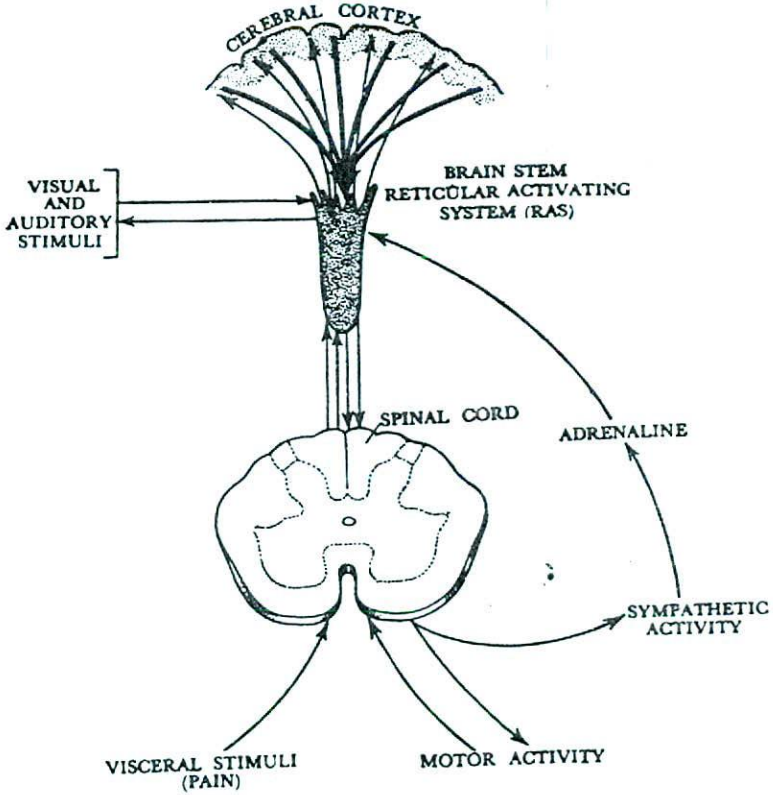


FIG. 5.182. Schematic representation of the feedback mechanism in the development of wakefulness and sleep.

Barbiturate anaesthesia depresses the reticular activating system by acting on the mesencephalic portion of the reticular activating system. Other anaesthetics probably have specific depressant effects on the mesencephalic reticular activating system.

THE DESCENDING RETICULAR SYSTEM

The importance of the reticular formation was first recognised when Magoun and Rhines (1946) observed inhibition of movement following stimulation of the ventromedial portion of the medullary reticular formation and facilitatory effects on stimulation of the tegmentum of midbrain

and pons, or of the hypothalamus and subthalamus. Thus the descending reticular system (Fig.5.183)comprises functionally two distinct descending reticular projections—such as (*i*) descending inhibitory reticular projection and (*ii*) descending facilitatory reticular projection. These descending reticular pathways are organised as reticulospinal tracts which modify the activities of the spinal motoneurone.

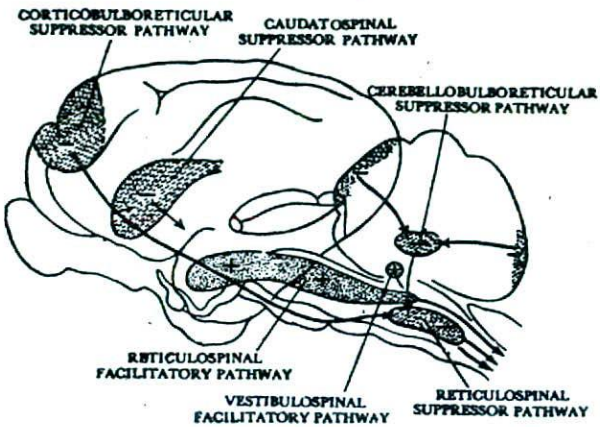


Fig.5.183. Diagram representing the facilitatory and inhibitory (suppressor) pathways of reticular formation (*after Best & Taylor*)

Descending inhibitory reticular projection (Fig.5.184A).If the ventromedial part of the medullary reticular formation, areas 4S, 2, 8, 19, 24 and caudate nucleus are stimulated then there is inhibition of movements induced reflexly or voluntarily or by stimulation of the motor cortex. The bulbar reticular inhibitory areas are under the inhibitory control of suppressor areas (4S, 2, 8, 19, 24) and caudate nucleus. These inhibitory areas are also under inhibitory control of the inhibitory projection fibres from the cerebellum through nucleus fastigius. The corticostrionigral and corticopontocerebellar pathways project over the bulbar reticular inhibitory system which relays in turn the fibres as reticulospinal tract to end finally on the γ-motoneurone of the spinal cord. Stimulation of any part of the inhibitory pathways leads to inhibition of γ-motor as well as muscle spindle discharge, and knee jerk reflex. Stimulation of the medullary inhibitory areas causes inhibition of extensor muscle tone in the decerebrate animal. The decerebrate rigidity is the release phenomena from the inhibition of the descending reticular inhibitory projection. In decerebrate rigidity the extensor muscle tone is increased due to γ-motoneurone activity.

Descending facilitatory reticular projection. Stimulation of the facilitatory areas causes increased γ-motoneurone activity producing increased extensor muscle tone, increased discharge from the muscle spindle and also inhibition of flexor reflexes. Descending facilitatory reticular projections are reticulospinal and vestibulospinal tracts (Fig.5.184B & C). Granit and Kaada (1952) have demonstrated that stimulation of the facilitatory areas causes increased γ-motoneurone activity as well as

proprioceptive input from the muscle spindle. The muscle spindle in return stimulates the α-motoneurone. Though the α-motoneurone is connected with either the descending facilitatory or inhibitory reticular pathways, yet the α-motoneurone is influenced through γ-loop system (FIG. 5.78) with the γ-motoneurone activity induced by the direct facilitatory or inhibitory influences of the descending reticular pathway. Functionally the stimulation of this pathway produces exaggerated movements and muscle tone. The decerebrate rigidity is the increased γ-motoneurone activity due to uninterrupted facilitatory effect of the descending facilitatory reticular projection, when inhibitory influences from descending inhibitory reticular pathways are cut off.

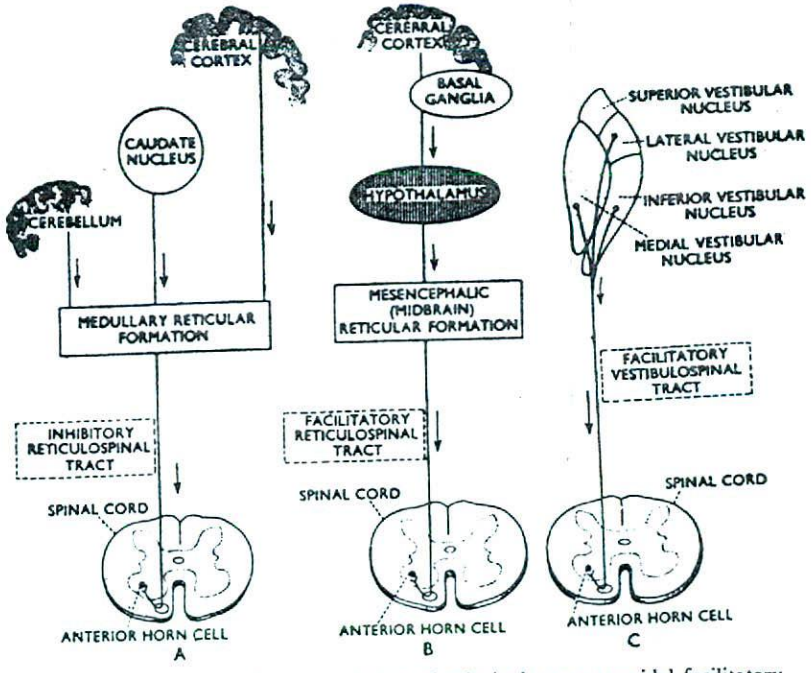


FIG. 5.184 Diagrammatic representation of principal extrapyramidal facilitatory and inhibitory pathways in the spinal cord.

It is believed that these facilitatory areas are connected with the reticular activating system because during activation of the reticular activating system, profound facilitatory motor activity is elicited. The facilitatory region of the brain stem reticular formation in turn stimulates the reticular activating system and cerebral cortex as well (Moruzzi and Magoun, 1949) causing wakefulness and alertness of the animal.

Functions of the reticular formation

1. Smooth and purposeful movements, posture and muscle tone are maintained by the balanced activities of the facilitatory and inhibitory descending pathways of the brain stem reticular formation.

2. Ascending reticular activating system maintains the alertness and wakefulness of the animal by any arousal reaction. Stimulation of reticular formation not only exerts wakefulness of the animal but it makes alert to the external environment that has been created during that period. It may be said that reticular formation is indispensable for initiation and maintenance of wakefulness. Damage to the reticular activating system produces sleep.

3. It is considered to be the higher centre for autonomic nervous system.

4. It is concerned with the regulation of different viscerovascular vegetative functions such as cardiac, vascular, respiratory, gastro-intestinal and metabolic.

5. It also plays in regulation of endocrine functions. Afferent connection from the reticular formation to the hypothalamus alter the anterior pituitary function particularly in the secretion of ACTH.

6. It is also concerned with the emotional and sex behaviours of the individual.

7. It has regulatory influence on the formation of conditioned reflexes and development of learning processes.

8. It also takes part in the control of the body temporature.

9. It also comprises the important nuclear group responsible for feeding thirst and satiety.

10. Reticular formation also controls the sensitivity of tactile receptors and of certain other sensory receptors such as in the retina and cochlea. It is also capable of modifying the conduction along various sensory pathways in the thalamus and sensory cortex.

MUSCLE TONE AND POSTURE

Muscle tone *is purely a reflex process.* It is produced by continual asynchronous discharge of motor impulses from the anterior horn cells, reflexly generated by a stream of sensory impulses arriving at them from the periphery through the posterior roots.

Thus muscle tone is maintained by the impulse activity of afferent nerves whose endings lie in the muscle spindles. Granit, Merton and co-workers have argued that the degree of muscle tone is largely determined by the state of activity in the γ-efferents which, causing contraction of the intrafusal muscle fibres, initiate Group Ia afferent discharge. This Group Ia afferent discharge reflexly excites the α-motoneurone supplying the extrafusal skeletal muscle fibres (Fig. 5.185). This reflex arc is monosynaptic and both afferent (Group Ia) and efferent (α-motor fibre) limbs of the arcs contain large fibres having diameter of

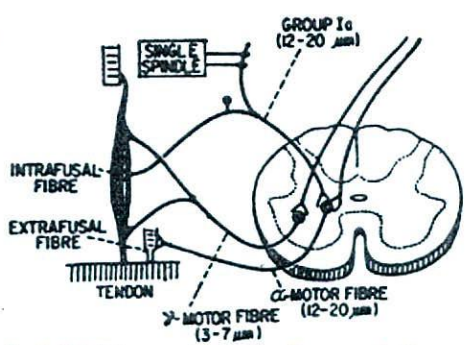


Fig. 5.185. Diagram shows the afferent and efferent mechanisms of stretch reflexes that maintain the muscle tone.

about 12-20 μm. γ-motor fibres contain small fibres having diameter of about 3-7 μm. Destruction of either the afferent (by tabes) or the efferent (due to trauma or poliomyelitis) limbs of the arc causes abolition of tone.

Thus muscle tone is abolished due to (*i*) destruction of posterior root carrying afferent fibres (Group Ia), (*ii*) destruction of motor nucleus or cell body in anterior horn cell, (*iii*) destruction of ventral root carrying both α- and γ-motor fibres, (*iv*) section of muscle nerve total.

1. Exaggerated muscle tone in Sherringtonian decerebrate (intercollicular) rigidity is due to excessive supraspinal drive on the γ-motoneurones, exerted by the preponderant activity of extrapyramidal facilitatory neurones on the hindbrain. Exaggerated muscle tone of decerebrate animal (intercollicular) can be abolished by local application of procaine and also by chlorpromazine which selectively paralyse the γ-efferent conduction.

Besides this, the muscle tone of this preparation can be abolished by cutting the dorsal roots (deafferentation), as because the exaggerated γ-efferent discharge causes stimulation of the Group Ia afferent which in turn excites the α-motoneurone.

2. Exaggerated muscle tone of ischaemic decerebrate preparation of Pollock and Davis (1930) is due to increased activity of α-motoneurone but not of γ-motoneurone as because deafferentation and chlorpromazine or procaine therapy fail to decrease the tone. Removal of bilateral vestibular apparatus or bilateral section of the VIII nerve causes the abolition of tone. In intercollicular decerebration if cerebellum is removed then identical state of affairs in muscle tone can be observed, because simple removal of both labyrinths abolishes the tone. This indicates that rigidity of ischaemic decerebration takes place by the overactivity of labyrinth on α-motoneurone; and this tonicity takes place in non-myotatic way (independent of stretch reflex). The rigidity of intercollicular decerebration is due to overactivity of γ-motoneurone through myotatic way and the activity of labyrinth on the α-motoneurone is suppressed due to presence of the cerebellum.

Thus muscle tone can be described as the partial tetanus of the muscle maintained by an asynchronous discharge of impulses in the motor nerve supplying the muscle. Though the tone is determined by both myotatic (stretch reflex) and non-myotatic (independent of stretch reflex) ways yet in ordinary circumstances it is maintained by myotatic way, i.e., through reflex activity of muscle spindle (stretch reflex). Cerebellum is the important site of α-γ linkage. In presence of cerebellum the muscle tone is maintained through α- and also by γ- activities (myotatic) but in absence of cerebellum the muscle tone is maintained by α-activity (non-myotatic) only. In ordinary circumstances the vestibular pattern of non-myotatic component is held in check by the cerebellum.

Granit has described that the state of muscle tone is mostly depending upon the γ-motoneurone activity which, through contraction of intrafusal fibres of the muscle spindle, increases the tone. Due to increase of the γ-motoneurone activity, the muscle spindle is stimulated and discharges impulses which cause reflex excitation of the α-motoneurone activity. Increased α-motoneurone activity in turn contracts the extrafusal fibres causing inhibition of discharge from the muscle spindle. The α-motoneurone also excites the Renshaw cells which in turn inhibit the α-moto-

neurone (FIG. 5.186). In this way the muscle tone is maintained. The α-motoneurone activity is also controlled with the activity of the cortico-spinal (pyramidal) tract.

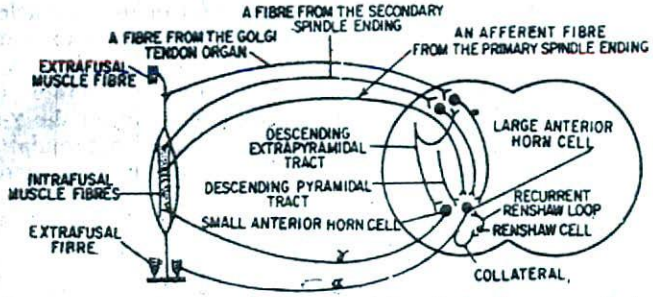


FIG. 5.186. Diagrammatic representation of the spinal reflex arcs and also of the role of Renshaw cell-inhibition in muscle tone and posture.

Though the muscle tone is originated from spinal reflex arc but it is continuously being regulated or modulated by the influences coming from supraspinal centres. Thus following spinal transection muscle tone is lowered below the section, and in section at intercollicular level muscle tone is exaggerated.

Autonomic nerves take no part in it. Since posture depends on tone and since tone is a reflex process, posture is essentially a reflex phenomenon.

The term **posture** *means an unconscious adjustment of tone in the different muscles concerned, accompanying every active movement, with the purpose of:* (*a*) *making the movement smooth and accurate,* and (*b*) *maintaining the line of gravity constant* (*equilibrium*). It should be noted that posture is not the active movement itself (which in most cases is a voluntary process) but is the associated redistribution of tone in the different groups of related muscles.

Postural mechanism. Being a reflex process, the postural mechanism must have: (*a*) afferent impulses, (*b*) nuclei, and (*c*) motor tracts. In addition to this, there are certain (*d*) higher centres which adjust the tone and produce a correct posture. It is the integrated activity of the multiple inputs from spinal, medullary, midbrain and cortical levels that regulate the posture of the body and make the co-ordinated movement possible. Smoothness and precision of movement depend upon the motor cortex as well as the cerebellum. Many of the fibres in the pyramidal system are also concerned with the control of posture.

Afferent impulses for muscle tone and posture (FIG. 5.187)

1. **Kinaesthetic impulses** are the main afferent impulses. Cutaneous impulses take no part. If a spinal animal (*vide* page 5-143)be skinned, rigidity of muscles persists. If then the posterior roots are severed, muscles become limp and the animal falls down.

2. **Impulses** (kinaesthetic) from the deeper parts of 'sole' take an important part in maintaining *erect posture.*

3. **Vestibular impulses** play an essential part in maintaining equilibrium, tone and posture. Any defect of the vestibular apparatus seriously disturbs the process.

4. **Retinal impulses** also play some part in maintaining posture. If a subject stands on tiptoe with the eye closed, balance becomes difficult (*Romberg's sign*).

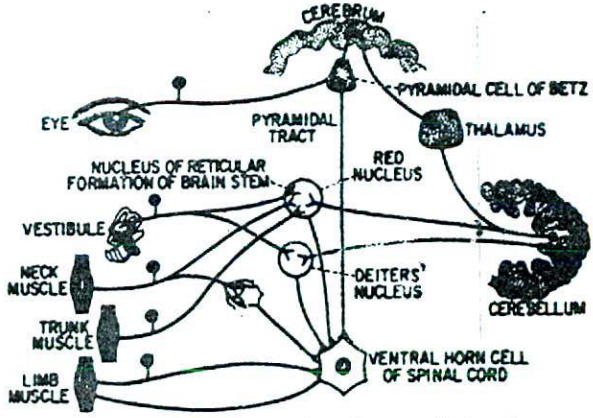


FIG. 5.187. Schematic representation of the regulation of posture (gamma-loop mechanism not shown).

Higher centres for muscle tone and posture

It has been studied by noting the effects of section at different levels of brain. When section passes above the thalamus, not much disturbance of tone and posture is noticed in lower animals, e.g., dog or cat.

Effects of lesions of the upper nervous system

After removal or sectioning the higher brain at a particular level, different experimental preparations can be made for studying the influence of the higher centres on the lower part of the nervous system.

Decorticate preparation. When the entire cerebral cortex is removed the animal can stand, walk but it shows appreciable rigidity owing to the hyperactivity of the anti-gravity or extensor muscles. Decorticate rigidity is present as a result of cortical area that inhibits γ-efferent discharge *via* the reticular formation. *Placing and hopping reactions* are seriously disrupted by decortication. The decorticate animal is blind and shows 'sham' rage when it is excited (FIG. 5.195). Decorticate rigidity may be seen on the hemiplegic side in humans after haemorrhage or thrombosis in the internal capsule. This rigidity is commonly seen in the animal at rest.

Hopping reaction. When a standing animal is pushed laterally, hopping movements keep the limbs in position to support the body. This response is called *hopping reaction.*

Placing reaction. If one limb of a standing animal is pushed out from under it, the limb is promptly replaced on the supporting surface in position to support the body. This response is known as *placing reaction.*

The placing reactions are usually abolished on one side by unilateral decortication.

Thalamic animal. *Vide* page 5-172 .

Decerebrate preparation. Section in between the superior colliculi and the inferior colliculi causes **decerebrate rigidity** (intercollicular) and this experiment was first performed by Sherrington in the cat in

1898. The limbs become hyperextended and the head is dorsiflexed (FIG. 5.188). In such decerebrate preparation the basal nuclei and cerebral cortex are removed. Respiration, swallowing and other medullary reflexes persist but temperature control and voluntary control of movements are lost. The limbs of this animal are extended, tail is raised and head is elevated (FIG. 5.188A). The muscles acting against gravity become rigid and the standing position is maintained only when the rigid animal is placed with its four feet on the ground. The exaggerated muscle tone is seen only in muscles that resist the effect of gravity and this tone is purely reflex in origin and γ-efferent activity is active in such preparation. If dorsal roots are cut then discharge from γ-motoneurone still persists (*vide* page 5-193) though the rigidity disappears; but if the cerebellum is subsequently removed then rigidity again reappears. This rigidity is due to α-motoneurone activity which takes place through non-myotatic way.

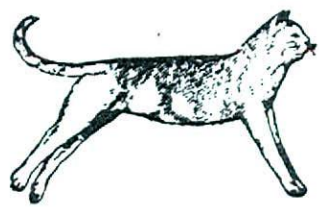


FIG. 5.188 A.

Pollock and Davis (1930) produced decerebrate rigidity in animals by tying the carotid artery and basilar artery at the junction of the pons and medulla. In such decerebrate preparation, a considerable part of pons as well as the more rostral part of the

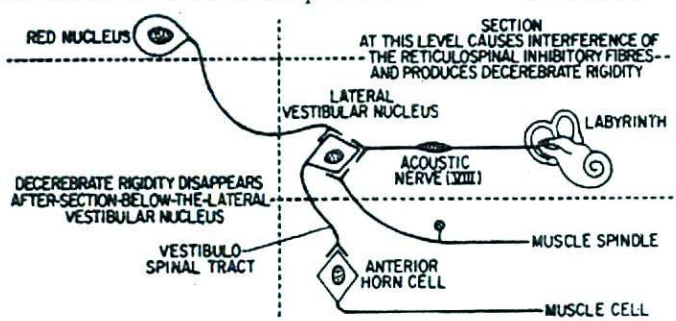


FIG. 5.188. Decerebrate rigidity in cat and the nervous pathways involved in its production.

brain stem and cerebral hemispheres and about half the cerebellum become ischaemic and for these reasons, this type of decerebrate rigidity is called **ischaemic decerebration.** The cause of rigidity in this preparation has already been discussed and is purely due to α-motoneurone activity and deafferentation does not abolish this spasticity but if the vestibular apparatus is removed or section made below the level of vestibular nucleus (FIG. 5.188) then spasticity disappears.

Thus posture is determined by the degree and distribution of muscle tone and depends on the pattern of discharge of motoneurones that supply the muscle. Motoneurone activity is reflexly regulated. Two groups of fibres arise in cells in the brain stem and descend to end in the vicinity of the spinal motoneurone. Since some cells in the brain stem are facilitatory and others are inhibitory, muscle tone and posture are under the balanced activity of the inhibitory and facilitatory areas of the brain stem reticular formation. Any condition which disturbs this balance, may affect the

normal muscle tone and posture (FIGS.5.183&5.184).Decerebrate rigidity is the overactivity of the facilitatory areas of the brain stem reticular formation because the activity of the inhibitory areas of the brain stem becomes out of control of the higher centres (cortical areas 4, 6 and caudate nucleus) due to transection at the superior border of the pons causing isolation of the hindbrain and spinal cord from the rest of the brain (section at the level XX of FIG. 5.189).Facilitatory areas of the brain stem reticular formation and also of the vestibular spinal facilitatory activating systems are excited causing exaggeration of extensor muscle tone (anti-gravity muscle) due to the γ-motoneurone activity. In such preparation the cerebellar (anterior lobe) inhibitory activity on the brain stem reticular formation as well as vestibular spinal facilitatory activity

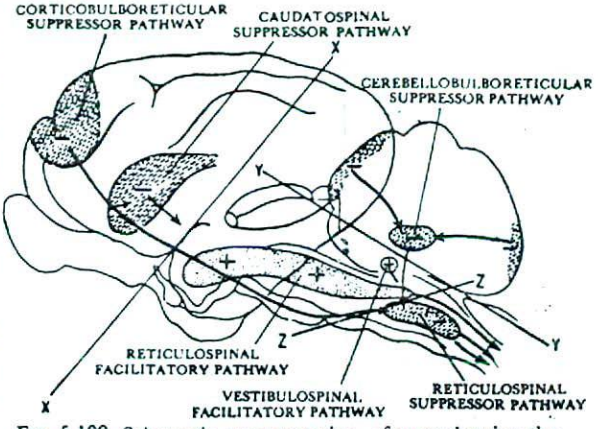


FIG. 5.189. Schematic representation of areas showing the localisation of facilitation (*plus sign*) and suppression (inhibition) (*minus sign*) of stretch reflexes (*after Ganong*).

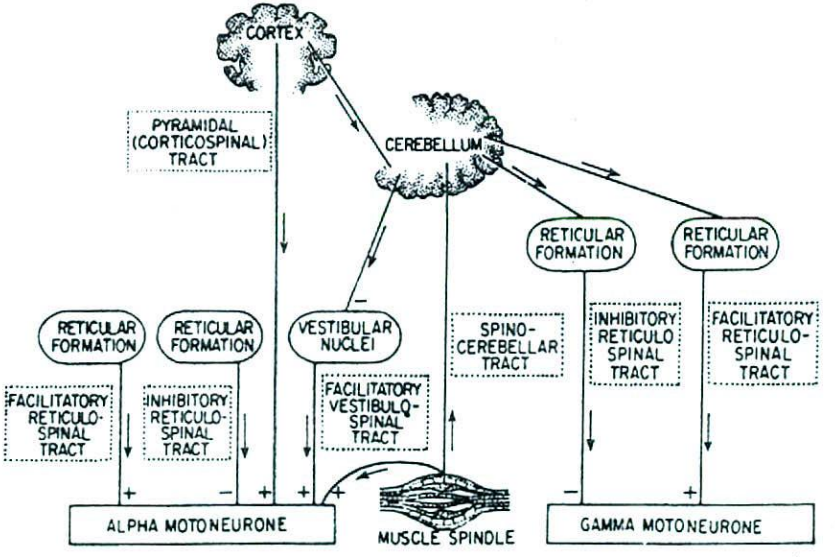


FIG. 5.190. Schematic representation of the activities of spinal alpha and gamma motoneurones and their pyramidal and extrapyramidal controls in the maintenance of muscle tone and posture.

are still existing (FIG. 5.190). If the anterior lobe of this cerebellum is removed at the level YY of FIG.5.189 then the rigidity is further increased. This rigidity is due to increased α-motoneurone activity (FIG. 5.190). But if the brain stem is transected at the level ZZ of FIG.5.189 then the tone is lost and muscle becomes flaccid.

Decerebrate rigidity is not commonly found in man and the pattern in true decerebrate rigidity is extensor in all four limbs like that in cats and dogs. Defects which produce decerebrate rigidity in man are not normally compatible with life. The actual decerebrate rigidity generally shows extensor rigidity in legs and moderate flexion in arms due to lesions of the cerebral cortex with most of the brain stem intact (FIG. 5.191).

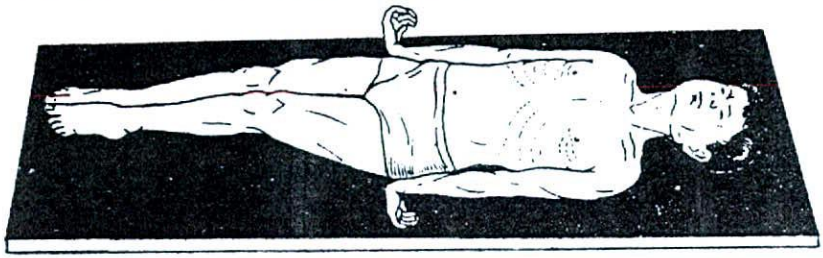


FIG.5.191.Diagrammatic representation of true decerebrate rigidity in man (*after Fulton*).

1. **Tonic labyrinthine reflexes.** Rigidity of the limb in decerebrate animals varies with the position. No righting reflexes are present and animal assumes its position in which it is put. If the animal placed on its back then there is profound extension of all four limbs(FIG.5.192A), but if the animal is turned on either side then the rigidity decreases. Rigidity is minimum when the animal lies in prone position. These changes in rigidity are due to the action of gravity on the otolithic organs. This reflex

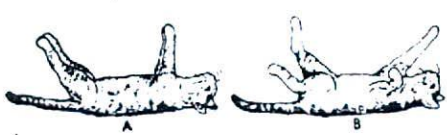


FIG. 5.192.



FIG. 5.193.

FIG. 5.194.

FIG.5.192.It shows the effect of position on posture of a decerebrate cat. If the animal is kept on its back (supine position) then it takes the typical posture as shown in the figure A. In the same animal after unilateral destruction of the vestibular nucleus, the animals assumes the above posture as shown in the figure B.
FIG.5.193.It shows the effect of neck reflexes on the posture of a decerebrate cat. If the pressure (↓) is applied on the neck then the animal takes a typical posture as shown in the figure.
FIG.5.194.It shows the effect of neck reflexes on the posture of a decerebrate cat. If the head is kept up keeping the nose raised then the animal takes a typical posture as shown in the figure.

rigidity is known as tonic labyrinthine reflexes. These reflexes can be abolished by removal of the labyrinth. Unilateral removal will cause abolition of the reflex of the same side(FIG.5.192B). Path is the vestibulospinal tract and the centre is medulla.

2. **Tonic neck reflexes.** If head of a decerebrate cat is turned to side, up or down then changes in rigidity are observed. This reflex is known as tonic neck reflexes. For this reflex study, labyrinth is removed. If the head is turned to the right, the right limb is extended and the left limb is relaxed. If pressure is applied to the neck, then all limbs are gradually relaxed (FIG.5.193).If the head is tilted so as to raise the nose then the forelimbs are extended while the hindlimbs are relaxed (FIG. 5.194).

Autogenic inhibition: Clasp-knife reflex. If the extended limb of a decerebrate animal is forcibly flexed then initially resists, but if more force is applied then the extended limb is suddenly collapsed like a spring-loaded folding knife blade. For this reason, it is also known as *clasp-knife reaction* of reflex. This is also called **lengthening reaction** as the extensor muscles are lengthened. Clasp-knife reaction or lengthening reaction takes place by the inhibitory impulses from the tendon-organ causing inhibition of the homonymous motoneurone supplying the stretched muscle. Such inhibition is also called *autogenic inhibition* and is a protective reflex. It protects the muscle from damaging contraction against strong stretching forces. Group Ib fibres innervating the Golgi tendon-organ constitute the afferent limb of the clasp-knife reflex or autogenic inhibition. It is mediated through a disynaptic reflex arc, whereas the myotatic reflex, mediated through the Group Ia fibres is monosynaptic. Group Ia carries sensation from the annulospiral region of the muscle spindle. Threshold for excitation of the Golgi tendon-organ and of annulospiral region is different. Under moderate stretching the annulospiral region is stimulated and precipitates the myotatic reflex as in case of knee jerk but in strong stretching Golgi tendon-organ is stimulated and the impulse is transmitted through Group Ib fibres causing reflex inhibition (autogenic inhibition) through activation of the internuncial neurones.

Midbrain component

Animals with intact midbrain as well as intact optic nerves show **pupillary light reflexes.** This type of response occurs in rotational acceleration (i.e., nystagmus).

In midbrain animal (after section of the neural axis at the superior border of the midbrain) extensor rigidity is present only when the animal lies quietly on its back.

Righting reflexes. Higher animals having righting reflexes can maintain normal standing position and keep their heads upright. These righting reflexes are mostly maintained by the nuclei of the midbrain.

Labyrinthine righting reflexes. If the midbrain animal is held by its body and tipped from side to side then the animal keeps its head in level (former position). This head reflex is known as *labyrinthine righting reflex.* Stimulus is tilting of head which stimulates otolithic organs and the centre lies within the midbrain.

Midbrain animal can right his head when the body is laid on one side even after labyrinthectomy. Pressure on the body initiates reflex righting of the head. This is **body-on-head righting reflex.**

Neck righting reflexes causing righting of thorax and shoulders, then pelvis due to stretch of neck muscles are rising in the midbrain.

Pressure on the side of the body may cause righting of body even if

the head is prevented from righting. This is the **body-on-body righting reflexes** whose centre lies in the midbrain.

If brain tissue in primates above the thalamus is removed and the animal is allowed to lie on one side, the limbs next to the supporting surface are extended. In such animals the upper limbs are flexed and the head on the upper side grasps firmly any object that comes in contact with it. This reflex is known as **grasp reflex.**

When a blindfolded animal is lowered promptly toward a surface it can see, its toes spread and its forelegs extend to support the body. This type of response to linear acceleration is called **vestibular placing reaction** which helps the animal to stand on the plane.

Flexion reflexes

The flexion or withdrawal reflex of the limb in man to a painful stimulus has already been described. Flexion reflex is studied utilising chronic spinal animals where the spinal cord is severed several days before the acute experiment. The reason for delaying the study of such preparations is to allow the animals to recover from the spinal shock. Spinal shock occurs immediately after spinal cord transection and is revealed by a profound depression of reflex activity; it disappears in a few days. Some of its characteristics as seen in the cat will be described below.

The reflex shows a threshold; to elicit it any stimulus should reach a certain intensity. The latency of the reflex (interval between the time of application of the stimulus and the start of reflex contraction) has the order of about 30 msec., more variable and much longer than the latency of contraction when a stimulus is applied to motor nerve. A stimulus is more effective the larger the area it occupies and the longer it lasts (spatial and temporal summation). When the stimulus is increased in intensity the flexion movement becomes more vigorous and more extensive. Thus a weak stimulus may cause movement of toes and ankle only, whereas with a very strong stimulus the knee and hip flex as well (irradiation). With the strong stimulus the limb may remain flexed for a second or more after the stimulus ends (after-discharge).

Fully-developed flexion reflex is accompanied by extension of the opposite leg, the ankle and knee straighten out and the limb is thrust backwards at the hip. This **crossed extensor reflex** has a much longer latency of 40–100 msec. than a *flexion reflex proper;* and once it begins it takes a second or two to build up to its greatest strength (recruitment), in contrast to the rapid onset of flexion. When the dorsal roots of that limb have been cut the crossed extension still occurs. The crossed extensor reflex may represent the first part of a step away from the noxious stimulus.

A reflex contraction of tibialis anterior can be produced by exciting any one of a number of peripheral nerves in that leg. Sherrington has described such impulses as *converging* on to tibialis motoneurones which formed a *final common path.* Although there is a true in a certain sense, but nowadays it is a less illuminating doctrine. As for instance in reflex action afferent impulses find their way through the spinal cord eventually to emerge *via* the motor roots.

Spinal preparation. Transection of the spinal cord at the midthoracic region produces flaccidity due to absence of different spinal reflexes.

But though animal recovers a part of its reflexes within a few days but reflex manifestation of supporting the body by the affected limb is absent (FIG. 5.195). In acute spinal preparation a shock stage prevails and duration of such stage depends upon the degree of encephalisation of motor

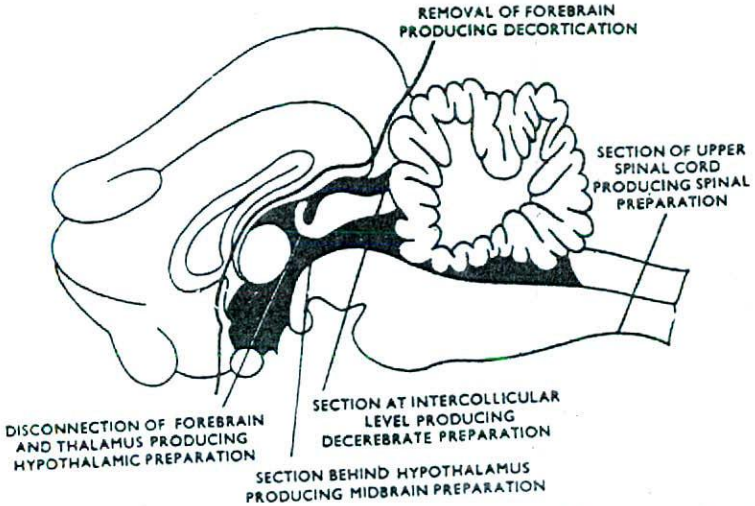


FIG. 5.195. Diagrammatic representation of sagittal section of brain stem showing different levels of transections (*after Carlos Eyzaguirre*).

function in different species. This stage lingers for a few minutes in frog, for 1-2 hours in cats and dogs, for days in monkeys and for a minimum of two weeks in man.

After recovery from spinal shock in animal and man or in the chronic paraplegic the withdrawal reflexes are present and threshold is greatly decreased. Stretch reflexes are heightened. The threshold stability of the withdrawal reflex is normally low in chronically quadriplegic human. Even minimal noxious stimulus may cause prolonged withdrawal of one extremity as well as flexion-extension patterns in other three limbs. Repeated flexion movement may occur for prolonged periods and there is development of flexor muscle contracture. There is also hyperactivity of the stretch reflexes.

For instance, if a finger is placed on the sole or on the palm of a spinal animal, the limb commonly extends following the examining finger. This is known as **positive supporting (magnet) reaction** which involves proprioceptive and tactile afferents. This type of reaction transforms the limb into a rigid pillar to resist gravity and also to support the animal. After the release of magnet reaction, there is also an active phenomenon partly due to **negative supporting reaction** which is initiated by stretch of extensor muscles. Owing to the magnet reaction the spinal cats and dogs can be made to stand, albeit awkwardly for 2-3 minutes.

In such spinal animals other reflexes like reflex contraction of the full bladder and rectum occur though incompletely.

Sexual reflexes like erection of penis and subsequent ejaculation are

also possible only after genital manipulation in male spinal animal and man. In female also irritation of the genitalia causes deviation of tail along with movement of pelvis in copulatory position

Besides these, there **mass reflex** occurs in spinal animal and man causing evacuation of bladder and rectum, sweating, pallor and raising of blood pressure due to mass irradiation of impulse in the autonomic centre.

Supraspinal control of the stretch reflex in relation to muscle tone and posture

The discharge of small anterior horn cells (determining the basis of the spindle sensory end organs) and the excitability of spinal interneurones are under supraspinal control. This controlling mechanism may be called the extrapyramidal system. Like muscle tone, the extrapyramidal system has been variously defined. The basal ganglia, their associated nuclei and the brain stem reticular formation, together with their descending spinal pathways may also be included. The vestibular nuclei and part of the cerebellum are intimately connected functionally with this system. This total group of structures represents a functional unit.

The extrapyramidal system exerts its influence on spinal neurones by virtue of the descending extrapyramidal pathways. The exact anatomy of these tracts is not fully known in man, nor it is possible to assign a particular function to any of them. Rather they may be considered as a mixture of excitatory and inhibitory fibres, impulses in the excitatory leading to an increased excitability of postsynaptic cells on which the fibres terminate and impulses in the inhibitory leading to a decreased excitability.

With the help of these descending pathways, the extrapyramidal system exercises its control over the stretch reflexes throughout the spinal cord, and normally sets the exciting effects in each segment at a level which is most suitable for the functioning of the body as a whole. In order to compute the most appropriate setting, the extrapyramidal system requires a sufficient inflow of information. Such a concentration of information appears to occur in the brain stem reticular formation, and the descending extrapyramidal tracts take origin mainly from this region. On animals two functional areas of the brain stem are termed as the inhibitory reticular formation and the facilitatory reticular formation. Stimulation of the inhibitory region against a background of the spinal stretch reflex activity reduces the reflex response. Stimulation of the facilitatory area enhances the reflex response. Information passes into these two regions and allows the computation of patterns of descending excitatory and inhibitory impulses. These impulses will set optimal spinal reflex excitability (FIG. 5.196).

The inflow of information into the smaller inhibitory reticular formation is from cortical inhibitory areas, corpus striatum (especially caudate nucleus) and the anterior lobe of cerebellum. The inflow into the facilitatory reticular formation is from the middle lobe of cerebellum and from the vestibular nuclei. The brain stem reticular formation also receives collaterals from the ascending sensory pathways where impulses are used by the ascending reticular activating system. This sensory information from the periphery may also be utilised by the brain stem reticular formation in determining the definite patterns of descending extrapyramidal impulses. In this way the reticular formation plays a role as a co-ordinating

centre or headquarters of the extrapyramidal system, collecting inflow of information from different sources and on the basis of this information directing the distribution and extent of stretch reflexes throughout the spinal cord.

From this point of view, postural reflexes, viz., tonic neck reflexes, tonic labyrinthine reflexes and righting reflexes are particular examples of total activity of the extrapyramidal system. With the difference these reflexes may extend further than simply altering sensitivities of the spinal reflex arcs and may lead to contraction of the extrafusal muscle fibres. However, there is no real discontinuity in the functioning of the extrapyramidal system, because the contraction of the extrafusal fibres is produced as a reflex following on imposed alterations in the length of the

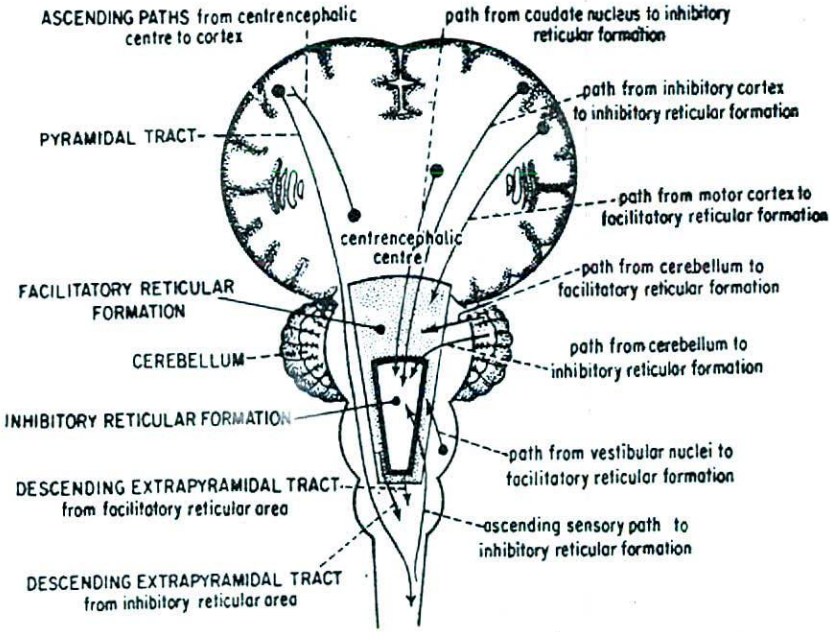


FIG. 5.196. Diagrammatic representation of a longitudinal section of the brain stem showing central organising areas and tracts.

intrafusal muscle fibres. This reveals that the descending extrapyramidal excitatory impulses have increased the small anterior horn cell discharge (and hence the intrafusal muscle fibre shortening) to such a level that the discharges from spindle sensory endings are enough in activating large anterior horn cells and hence cause shortening of the extrafusal muscle fibres. This type of activity of the extrafusal muscle fibres will continue until the stretch on sensory endings (imposed by intrafusal muscle fibres) is removed, with the recurrent cessation of afferent discharges.

When this begins to appear to be the most common method of producing postural reflex activity in the normal subject, postural adjustments can also be obtained by direct descending extrapyramidal activation of

large anterior horn cells. In the experimental subject, the anterior lobe of the cerebellum participates in determining by which route (γ or direct α) the extrafusal muscle fibres shall be activated. Since transmission over γ-fibres and reflex arc imposes a delay on the initiation of the skeletal muscle movement, so it may be noted that at least some of the descending extrapyramidal tracts are composed of large diameter and hence rapidly conducting nerve fibres, with which the desired postural adjustment is possible.

In summary, the extrapyramidal system may be considered as the controlling mechanism determining the setting of stretch reflexes. The set includes the sensitivity of the primary spindle ending to stretch and the excitability of the appropriate interneurones. This is a sensitivity of the reflex arc to stretch. If a limb is absolutely at rest, with all sources of muscle stretch removed, the muscle fibre will be electrically silent with no motor unit activity. However, any stretch will result in a reflex contraction and the extent of this contraction will be determined with the setting imposed upon the sensory end organs by the extrapyramidal system. It may be believed that the static response of stretch reflex will be voluntarily inhibited by inhibiting interneurones. The extrapyramidal system can also facilitate the response to superadded stretch, and does also increase afferent discharge from sensory endings to an extent such that actual reflex contraction of the extrafusal muscle fibres will be produced (postural reflexes). Since the inflow of information to the reticular formation comes from a wide variety of sites and the correct action by the reticular system depends upon a full and accurate inflow from such sources, so the reticular formation allows inflow continuously to adjust tone throughout the body during walking periods.

From the above dissertation it is clear that in addition to emmense roles of the brain stem reticular formation and spinal cord, the following centres play an important part in the maintenance of posture, tone and equilibrium.

1. **Cerebellum.** Palaeocerebellum is connected with the spinal cord and vestibular apparatus and as such, plays an essential part in equilibrium and posture. Disease or injury to this part seriously disturbs the process. Neocerebellar defects also disturb it considerably (*vide* pp. 5-168 -169).

2. **Vestibular nuclei.** Role of vestibular nuclei in the maintenance of muscle tone and posture has been discussed. Unilateral destruction of the vestibular nucleus causes abolition of rigidity of the same side. Vestibular nuclei exaggerate muscle tone in ischaemic decerebration through facilitatory vestibulospinal tract acting on α-motoneurone.

3. **Basal ganglia.** Being an important organ for extrapyramidal control, it takes an important role in the postural mechanism. Striatal diseases (viz., Parkinson's disease) are characterised by muscular rigidity, tremor, etc. [*Vide* pp. 5-181 - 182.]Diseases of the basal ganglia lead to abnormal movement—hyperkinetic, like chorea, athetosis and ballism. Hypokinetic disease like Parkinson's disease (paralysis agitans) is also observed.

4. **Cerebrum.** The cerebral cortex, in man and higher animals, with well-developed pyramidal and extrapyramidal areas, exerts immense influences on all the lower centres of brain and spinal cord, and thus exerts considerable influence on tone and posture. Injury or disease of these areas is associated with defective tone and posture. Decorticated ape or man

thalamic man) develops a rigidity similar to decerebrate rigidity (legs extended, forelimbs flexed).

Fast' (white or pale) and 'slow' (dark or red) muscles

In some animals two distinct populations of the striated muscle may be found : (*a*) the slowly contracting red or dark (*slow*) muscle, and (*b*) the rapidly contracting white or pale (*fast*) muscle. In such species the *slow* (red) muscles may play a major role in the maintenance of static stretch reaction. The tonic motoneurones of the slow red muscle are functionally distinct from phasic motoneurones of the fast pale muscle and receive a disproportionately large monosynaptic inflow.

In man and monkey, most muscles are composed of slow and fast muscle fibres. The slow fibres are rich in sarcoplasm with poorly marked transverse striations, whereas the fast fibres are poor in sarcoplasm with well-marked striations. The slow or red fibres, being slow-active in nature, are suitable for maintaining posture : The fast or pale fibres, being rapid-acting in nature, are suitable for rapid phasic movements.

Postural reflexes

All postural reflexes are *stretch reflexes. They are divided into two groups :*

I. **Static reflexes** (when the body is not in locomotion)

1. Local static reactions—confined to one limb.
2. Segmental static reactions—confined to one segment (e.g., both hindlimbs or forelimbs).
3. General static reactions :

(*a*) Attitudinal reflexes e.g. Tonic neck and tonic labyrinthine reflexes.
(*b*) Righting reflexes.

II. **Statokinetic reflexes** (when the body is in locomotion)

1. Reactions to rotation :

(*a*) Head reactions. (*b*) Eye reactions.

2. Reactions to progressive movement :

(*a*) Reactions of head. (*b*) Reactions of extremities.

Though postural adjustments are very rigid to separate from voluntary movements, yet it is possible to differentiate a series of postural reflexes (*vide* table in P.5-206) which include maintained static reflexes and dynamic short-term phasic reflexes. The static reflexes involve sustained contraction of the musculature, whereas the phasic reflexes involve transient movments. Postural reflexes not only maintain the body in an upright, balanced position but provide the constant adjustments necessary to maintain an appropriate postural background for voluntary activity. Both static and phasic reflexes are integrated at various levels in the central nervous system from the spinal cord to the cerebral cortex and are effected greatly through extrapyramidal pathways. At the spinal cord level, the extrapyramidal afferent impulses produce simple reflex responses. At higher levels in the central nervous system, neural connections of increasing complexity mediate increasingly complicated motor respones. Different postural reflexes with their centres are presented in page 5-206

Righting reflexes

The body has the ability of reflexly coming back to its upright position when the erect attitude is disturbed. This can be well demonstrated in *thalamic animals.* When such an animal be laid on its side, the head at once rights itself followed by the body, gradually assuming the upright

SOME POSTURAL REFLEXES

Reflex	*Centre*	*Receptor*	*Stimulus*	*Response*
Optical righting	Cerebral cortex	Visual cues	Opening of eyes	Righting of head
Placing reaction	Cerebral cortex	Proprioceptive, exteroceptive and visual cues	Pressure like touch, push, etc.	Limb replaced on the supporting surface in position to support body
Hopping reaction	Cerebral cortex	Stretch in muscles	Lateral pushing while standing	Movements keep limbs in position to support body
Labyrinthine righting	Midbrain	Otolithic organs	Tilting of head	Compensatory contraction of neck muscles to keep head level
Neck righting	Midbrain	Stretch of neck muscles, muscle spindle	Righting of head and tilting of body	Righting of thorax and shoulders, then righting of abdomen and hind quarters
Body-on-head righting	Midbrain	Exteroceptors	Pressure on the side of body	Righting of the head even after destruction of labyrinths
Body-on-body righting	Midbrain	Exteroceptors	Pressure on the side of body	Righting of the body even if the head is prevented from righting
Tonic labyrinthine	Medulla	Otolithic organs	Gravity *via* vestibulospinal tract	Extensor rigidity
Tonic neck	Medulla	Stretch of proprioceptors in upper part of the neck	Head turned to one side, upward and downward	Alteration in the pattern of rigidity : Extension of limbs on that side (Jaw limbs) to which head is turned. Extension of head leads to flexion of hindlimbs and extension of forelimbs. Flexion of head causes continued extension of hindlimbs and flexion of forelimbs
Stretch	Spinal cord, medulla	Muscle spindle	Stretch	Contraction of muscles
Magnet reaction or positive supporting reaction	Spinal cord	Proprioceptors in distal flexors and tactile afferents	Pressure on sole or palm	Extension of limbs to support body
Negative supporting reaction	Spinal cord	Proprioceptors in extensors	Pressure withdrawn, from sole or palm	Release of magnet reaction

position. This reflex is called **righting reflex.** It consists of a series of reactions with the following regular sequence:

1. **Head righting reflex.** At first the head ri. ts itself by the following three ways:

(*a*) *Labyrinthine righting reflex*—Position of the head being disturbed, impulses arise from the saccules and reflexly right the head.

(*b*) *Body righting reflex*—The animal being on the ground, kinaesthetic impulses arise from the lower side due to contact with the ground. But no such impulse originates from upper side. This *asymmetric series* of impulses stimulate the reflex and right the head. In this way, the head can be righted even after double *labyrinthectomy*. The impulse must be asymmetric. If both sides be symmetrically stimulated, the head remains in the lateral position and is not righted.

(*c*) *Optical righting reflex*—In the labyrinthless cats, dogs and monkeys, head righting reflex can still occur if the eyes are open but not when they are closed. The centre lies in the visual cortex, from where impulses pass to the neck muscles to right the head.

2. **Neck righting reflex.** The above three reflexes act primarily on the neck muscles and correct the head position. The trunk being still in the lateral position, the neck gets twisted. This generates fresh impulses and reflexly brings the thorax and then the lumbar region successively into the upright position. [If the righting of the head be prevented, impulses from the body surface may cause righting of the body directly.]

3. **Limb righting reflex.** The impulses arising from the limb muscles themselves are chiefly responsible for the righting of the limbs.

The chief centre for righting reflexes lies in or near the red nucleus (FIG. 5.187)

Control or co-ordination of willed movement

A willed movement is superimposed on a background of muscle tone and postural reflexes. A willed movement itself inevitably causes alterations in muscle tone in order that the movement may be commonly performed. In other words, a normal willed movement involves simultaneous correct functioning of the pyramidal and of the extrapyramidal system. Concerning the normal function of the extrapyramidal system an imposed willed movement is one of the varieties with which the brain stem reticular formation has to deal and the postural alterations accompanying a volitional act are not quite different. Prior knowledge of intended willed movements constitutes an additional inflow of information to the reticular system when the optimal postural adjustments are computed. Though the anatomical pathway for this inflow is ill-defined, yet according to Penfield there is a **centrencephalic integration system** at the level of the higher brain stem in which situation it might overlap with the *facilitatory reticular formation*. This postulated centrencephalic system may be defined as a functional, sensory integrating area, which serves as the site for the initiation of willed movement. The will to initiate a movement is believed to originate in this area, and impulses of the nerve fibres pass from the centrencephalic area to the motor cortex. From the motor cortex nerve impulses pass down in the pyramidal tract to the anterior horn cells. Though this postulated centrencephalic system does not bear any strict anatomical reality, some such centrally placed structure must be implicated in the organisation of simultaneous bilateral willed movements. Furthermore, while stimulation has been applied to the exposed motor cortex of conscious man there is

some inflow to the motor cortex from lower centres. Liminal stimulation of an area on the motor cortex may lead to a fragmentary contraction of a muscle or muscle groups (excitatory points) or simply to the inhibition of willed movements in a particular part of the muscular system (inhibitory points). Lastly, stimulation of certain areas of the motor cortex seems to fire off inborn bilateral (possibly brain stem) mechanism responsible for sucking, swallowing, etc.

The centrencephalic system may call upon two primary motor cortices: (*a*) Rolandic motor cortex is not the only area of the cortex responsible for giving rise to activity in the skeletal muscle while stimulated. Willed movements may also be produced from the supplementary motor area and probably from the second sensory and mesial temporal areas. (*b*) Large Betz cells (area 4) give rise to only about 4–5% of fibres of the pyramidal tract, and majority of the descending fibres have small diameter and hence slowly conducting. Pyramidal fibres terminate either directly on the surface of anterior horn cells or indirectly *via* interneurones.

The pyramidal tract terminations might be with either large (α-) motoneurones or small (γ-) motoneurones. In the former case, willed contraction of the skeletal muscle might be caused by directly activating the α-motoneurones and the final common path, whereas in the latter case the contraction might be caused by a reflex following such as is stated for postural movements. Under these circumstances, the descending pyramidal impulses might increase the discharge of γ-motoneurones. This will lead to intrafusal fibres shortening and a resultant increase in afferent discharge from the muscle spindles. The increased afferent discharge, reaching the α-motoneurones over the *fast monosynaptic pathway*, will produce a reflex (following) contraction of extrafusal fibres. The contraction of the extrafusal fibres will then be maintained as long as the increased discharge from the γ-motoneurones will be continued. This type of contraction of the extrafusal fibres may be stated as **a follow-up length servo,** i.e., a system controlled by negative feedback. The term *follow-up length servo* was introduced by Merton to describe the *modus operandi* of γ-loop mechanism. He considered the muscle spindles to serve as misalignment receptors. The apparent advantage of the follow-up method will seem to be that it offers a more accurate control of the movement, since inflow of information is being fed back from the muscle spindles about the progress being made during movement. There is no inevitable evidence of such behaviour on which to decide which of these two (direct or indirect) possible mechanisms is used under specified circumstances. Because a willed movement can be directly produced in deafferented limbs, though the execution of such mechanism is not precise.

SUMMARY. The will to initiate a willed movement originates in a functional, sensory integrating area named the centrencephalic region. From this area, nerve impulses pass out to the motor cortex and to the brain stem reticular formation. The latter structure—on the basis of its sensory inflow—gives rise to a pattern of descending excitatory and inhibitory extrapyramidal impulses which set the excitability of the various stretch reflexes. Meanwhile, the motor cortex discharges, down the slowly conducting pyramidal tract, a pattern of impulses, which, acting initially either on α- or γ-motoneurones, leads to the ultimate activation of the *prime mover* muscles.

VESTIBULAR APPARATUS

Introduction. It consists of rigid **bony labyrinth** which lodges a number of hollow membranous structures called **membranous labyrinth** (Figs.5.197& 198). The bony labyrinth includes (*a*) the **vestibule,** (*b*) the bony **semicircular canals,** and (*c*) the **cochlea.** These three communicating cavities are filled up with **perilymph** which is clear fluid of high sodium. The bony labyrinth communicates with the cerebrospinal fluid by

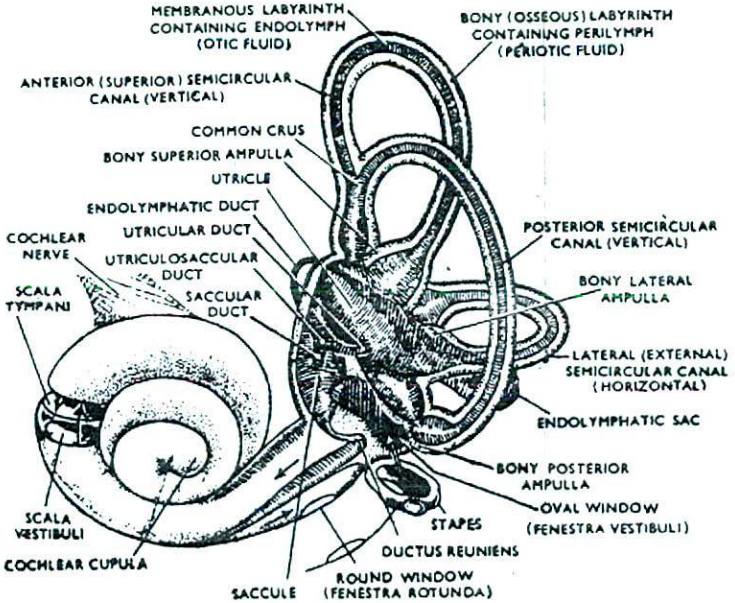


Fig.5.197. Diagrammatic representation of bony and membranous labyrinths showing vestibular otolithic organs and endolymphatic sac and duct. Oval window showing removing stapes.

way of the cochlear aqueduct. The membranous labyrinth(Fig.5.198) lies within the bony labyrinth, and consists of the **cochlear duct, otolithic organs**—saccule and utricle and the three **semicircular ducts**—whole thing being situated within the vestibule as a closed system. The membranous labyrinth is an endolymphatic duct ending in a depression in the petrous bone surrounded by a venous plexus and is filled up with **endolymph** which has a high potassium. The posterior and superior canals are situated in vertical planes at 90° to one another and the horizontal or lateral canal lies in a plane passing backwards and partly down.

Each semicircular duct is about 15 mm long in the human and smaller in diameter than the bony semicircular canals. Each duct has a wider portion or **ampulla** which contains ampullary crests (cristae ampullares). The crista is situated at the dilated end of each semicircular canal and possesses hair cells enveloped with a mass of gelatinous substance **cupola.** Each hair cell carries numerous fine cilia about 0·2 μm in diameter with a stronger cilium nearer the utricle. The cupola comprises a network of fine fibres having a diameter of 10 nm and is

embedded in a protein matrix (possibly sulphomucopolysaccharide). The otolithic organs (saccule and utricle) possess **maculae** with bottle-shaped and cylindrical hair cells separated by supporting cells and covered with

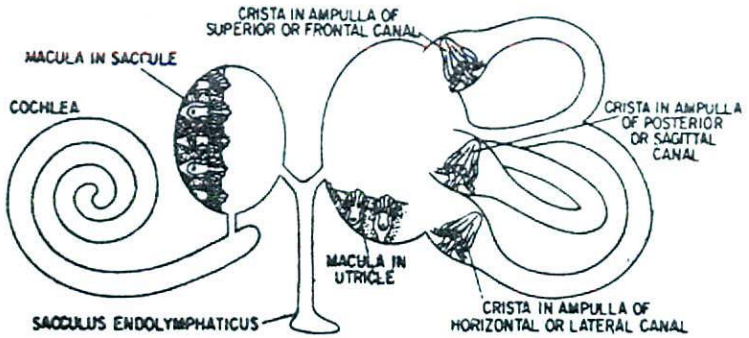


FIG. 5.198. It shows the membranous labyrinth (diagrammatic).

a layer of jelly-like substance containing particles of otoconia (calcium carbonate).

When the fine nerve filaments from hair cells in the cristae and maculae pass centrally in the vestibular nerve to the vestibular ganglion and then to the vestibular nuclei become myelinated (FIG. 5.199). From these nuclei (1) some sensory fibres run in the medial longitudinal bundle to the oculomotor

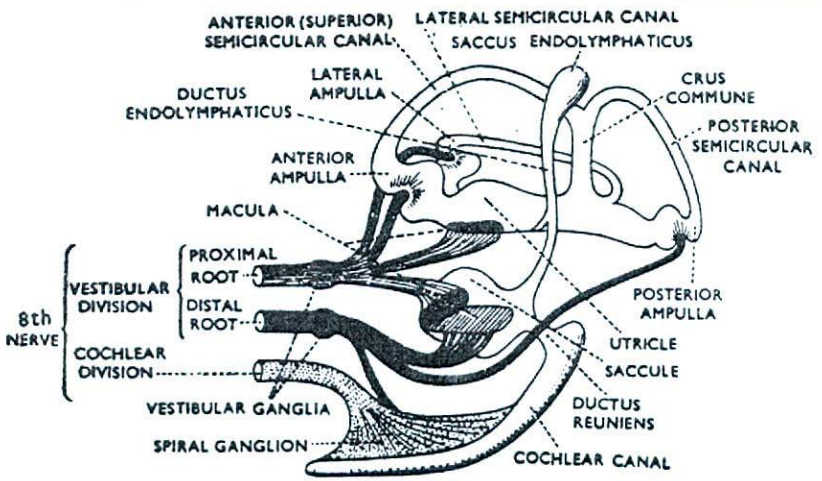


FIG. 5.199. Schematic representation of membranous labyrinth with nerve supply.

nuclei through which changes in position of the eyes are effected. This is the pathway of nystagmus and counter-rolling. (2) A group of sensory fibres also run in the medial lemniscus to the thalamus. (3) Other sensory fibres pass in the inferior cerebellar peduncle to the cerebellar cortex, mainly to the flocculonodular lobe. (4) Some of sensory fibres go in the reticular formation. (5) Another group of sensory fibres pass in the

vestibulospinal tract. In addition to these sensory impulses, efferent impulses from the lateral vestibular nuclei reach the hair cells.

In the erect position in man the macula of the utricle is more or less horizontal so that the hair cells project vertically upwards with the otoconia and the macula of the saccule lies in a vertical plane (Fig.5.198). The discharge rate from nerve endings changes according to the gravitational pull on the otolithic organs. Adrian (1943) recorded impulses from very small electrodes placed on the vestibular nucleus in the floor of IV ventricle of a cat. It has been observed that the first form of response comprises slowly adapting impulses arising from gravitational pull on the otolithic organs, and depends on the position of the head in space and signals tilting and linear acceleration. The other type of response is rotation-controlled type, and angular acceleration produces this response and the position of the head does not affect. These impulses come from the cristae of the semicircular ducts because they are most sensitive to rotation in one particular plane. Rotational movement in the plane at right angles produces no or little alteration of resting discharges. Rotation in the direction which displaces the cupola towards the utricle increases the frequency of discharge, rotation in the opposite direction diminishes the frequency of discharge. If a rotation which produced an increase in frequency is arrested, the rate of discharge declines and it normally takes 10–30 seconds to regain the normal resting discharge rate.

When the head is rotated, the perilymph and endolymph in the semicircular canal lying in the plane at right angles to the axis of rotation appear to lag behind the movement of the head; the cupola is, therefore, deflected and the hair cells are stimulated.

Movement of endolymph and of the cupola from the stereocilia to the kinocilium gives a drop in the potential and increases afferent discharge. Since all the hair cells are situated in the same way, all respond similarly to a certain displacement. In such a way the semicircular canals give information about the angular acceleration of the head in space. If the rotational movement is continued to reach a steady angular velocity the lymph moves with the canal, the cupola comes back to its normal position and the stimulation of the hair cells ceases. However, the duration of subjective sensation of turning is related to the time taken by the cupola to regain its resting position.

When the rotation of the head ceases the fluid, due to its momentum, continues to move and deflects the cupola in the opposite direction. Though the cupola has been compared to a swing door or a highly damped pendulum, but it probably does a fairly tight seal across the ampulla because India ink injected into the endolymph on one side of the cupola does not run readily in the other side. Rotation of the head seems to produce a sliding movement rather than a deflection of the cupola.

Functions. (1) Takes an essential part in the maintenance of muscle tone, posture and equilibrium. (2) Reflexly (*a*) adjusts the relative position of head to that of trunk and limbs, (*b*) maintains the erect position of the head. (3) Sends impulses to cortex giving information about the position (otolithic organs) and rotation of head in a particular plane (semicircular canals).

Vestibular function tests. Disturbance of labyrinthine function, with intermittent attacks of rotational vertigo, nausea or vomiting, and

nystagmus are common, because the vestibular apparatus and the cochlea share the same circulation.

The most common vestibular function test is the **caloric tests.** The subject lies supine with his head 30 degrees forward, to bring the lateral semicircular canal into a vertical plane with the ampulla uppermost (FIG. 5.200). so that it responds best to thermal stimulation. A stimulus of cold water 7°C. below body temperature (i.e., 30°C.) and then after an interval, a stimulus of warm water 7°C. above body temperature (i.e., 44°C.) is applied through a tube directly to the tympanic membrane and so indirectly to each labyrinth. Syringing the ear with warm water causes a flow of endolymph towards the ampulla of the lateral canal and a deflection of the cupola with nystagmus to the same side. In the normal subject, this produces horizontal nystagmus lasting about 2 minutes (FIG. 5.201). Placing electrode on the skin at the outer canthi of eyes, the eye movements can be recorded and this is known as **electronystagmography.**

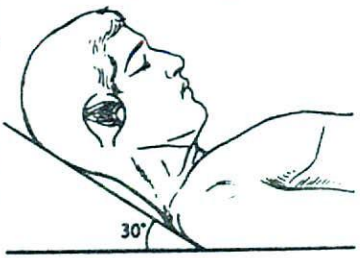


FIG. 5.200. It shows vestibular function test. The subject lies supine with his head raised 30° so that crista is horizontal.

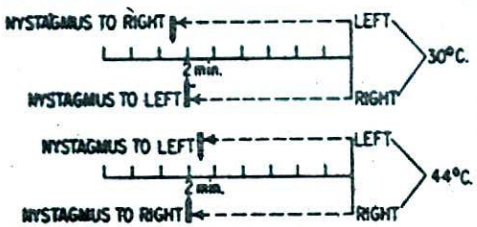


FIG. 5.201. Caloric tests. Normal average response to stimuli applied separately to each tympanic membrane. The dotted lines show the duration of after-nystagmus from the beginning of the stimulus.

The caloric test has great value in the diagnosis of organic lesions at all levels of vestibular system and in peripheral lesions (e.g., semicircular canal paralysis, etc.).

THE SEMICIRCULAR CANALS

Anatomy. There are three semicircular canals *lying in the three planes at right angles to one another* (FIG. 5.202). The canals are **lateral, anterior** (superior) and **posterior.** The lateral (external) canal is horizontal. The other two are vertical and make an angle of about 45° with the frontal and sagittal planes. The anterior canal of one side is in a plane approximately parallel to the plane containing the posterior canal of the other side. Thus the six canals on two sides remain arranged in three planes, making three functional pairs (FIGS 5.202 & 5.204). Each canal begins in a dilatation called the **ampulla.** In the ampulla there is located the specific sense organ—the *crista ampullaris.* The ampullae of the corresponding canals lie facing each other. The three canals open into the utricle by *five apertures* (not six), one aperture (*common crus*) being same to the two vertical canals (FIGS. 5.197 & 5.199). The utricle communicates with the saccule through the utriculosaccular duct. The endolymphatic duct (*ductus endolymphaticus*) arises from the utriculosaccular duct and ends as a blind sac—the endolymphatic sac (*saccus endolymphaticus*). The saccule communicates with the duct of cochlea through *ductus reuniens* (FIGS. 5.197, 5.198, 5.199 & 5.203).

Histology (FIG. 5.205). Each canal has three layers: (1) Outer coat consists of blood vessels and loose fibrous tissue. (2) Middle coat is thick,

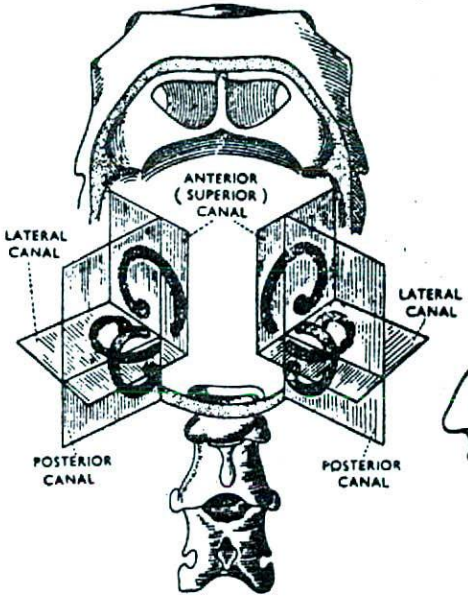


FIG. 5.202. Showing the arrangement of the three semicircular canals in three planes at right angles (*after Starling*).

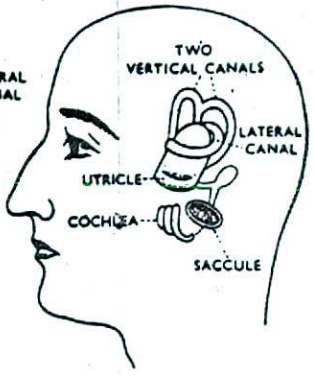


FIG. 5.203. Shows the relative position of cochlea and vestibular apparatus on the left side (*after Best & Taylor*).

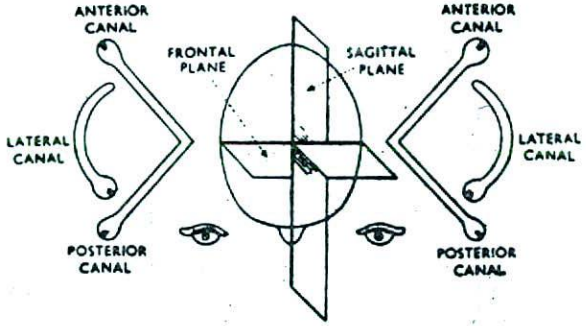


FIG. 5.204. Arrangement of semicircular canals on two sides—making three functional pairs. Anterior canal of one side is in the same plane as the posterior canal of the other (*after Best & Taylor*).

homogeneous and transparent and forms the basement membrane. (3) The inner layer is made up of cubical epithelium. The histological structure of **ampulla** shows the presence of the sense organ—**crista ampullaris.** It consists of a ridge of neuroepithelium and is surrounded at its base by the *planum semilunatum*, which is a secretory epithelium. The neuroepithelium

comprises two types of hair cells—one is *flask-shaped* **(type I of Wersall)** and the other is *cylindrical* **(type II).** Both types of vestibular sensory cells

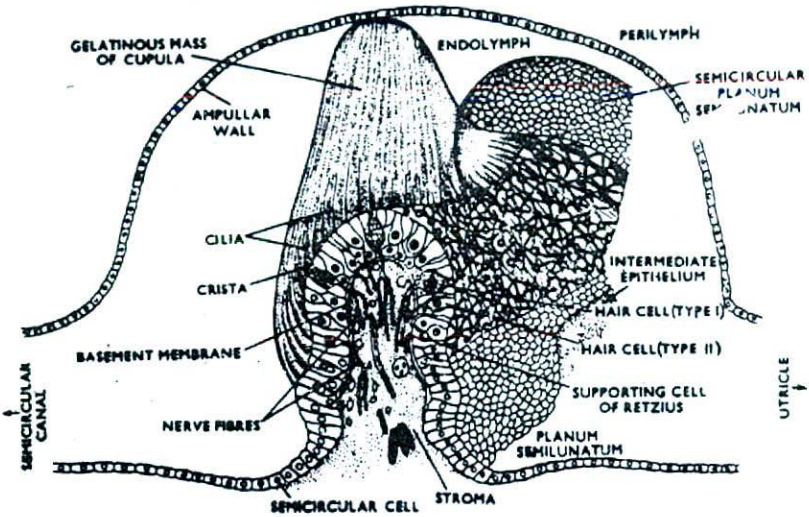


FIG 5.205. Histological representation of one-half of an ampulla crista in a longitudinal section of a semicircular canal which passes across the crista *(after Carlos Eyzaguirre)*.

bear hairs—the **kinocilium** (single hair) and **stereocilia** (40–60 hairs). Kinocilium is thicker and single while the stereocilia are numerous and thinner (FIG. 5.206). When movement of the lymph occurs towards a kinocilium the discharge increases, and when it occurs towards the thin

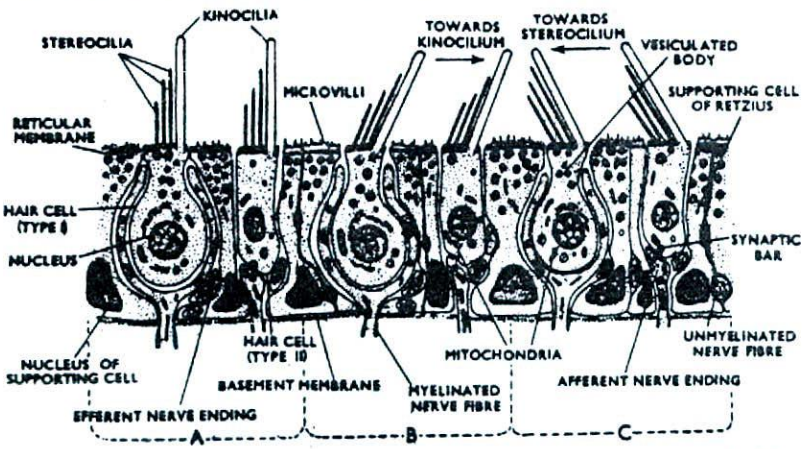


FIG.5.206. Schematic representation of two types of hair cells showing relationships between afferent (sensory) and efferent nerves which terminate on the sensory cells and also the pattern of stimulation of and displacement of the sensory nerve fibres. A in resting activity, B in stimulation depolarisation. C in inhibition hyperpolarisation.

stereocilia the discharge declines. Between the hair cells lie the **supporting cells of Retzius** with their nuclei at the base and microvilli at the apices. A *mucoid-gelatinous mass* with its fine parallel channels encloses the long sensory hair. This soft mucoid material which is known as **cupola,** is a dome-shaped structure and extends upward from the *crista* to the roof of the ampulla. It had long been known as histological artifact but at present it has been regarded as essential moving part in the stimulation of the hair cells. The sensory nerve endings attached to the hair cells send impulses into myelinated nerve fibres having diameter of 2 to 9 μm.

Mode of action (FIG. 5.207). Change of pressure of the endolymph (*otic fluid*) acts as the stimulus. Since endolymph has inertia, when the head is rotated, the endolymph lags behind. Consequently, when the rotation is from left to right, pressure in the right ampulla increases, while that in the left falls. These opposite pressure changes stimulate the cristae which send up impulses to the brain giving information about movements of the head in that plane.

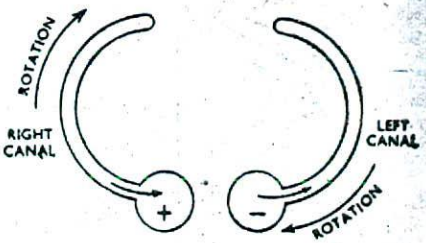


FIG. 5.207. Mode of action of semicircular canals. '+' indicating increased pressure; '—' fall of pressure.

Semicircular canals may be stimulated in a subject by rotating him in a special chair at a quick speed (say one revolution in 2--3 seconds). If the subject is rotated to his left both eyes move slowly to the right. This is followed by a quick movement of the eyes to the left which brings the eyes back to the middle position. Another slow and quick movement takes place and so on. This phenomenon is called the **vestibular nystagmus.** Conventionally, the direction of nystagmus indicates the direction of rapid component. The slow movement of nystagmus shows the vestibular activity when the central correcting factors bring about the rapid jerk back to the central position. When the rotation to the left is suddenly blocked the labyrinthine sensory impulses are altered as if the rotation were now to the right, and nystagmus takes place in the opposite direction. As soon as the direction of rotation is arrested, the head, body and arms tend to move in that direction just ended. The person feels that he is still moving (vertigo) and may fall over if the subject attempts to stand up. This disturbance of equilibrium is brought about due to the confusion between labyrinthine and visual signals.

During rest, the whole of the vestibular system is in a state of tonic activity. This activity is manifested by a steady discharge of action potentials in its peripheral neurones. The vestibular tone of both sides has equal and an opposite action on skeletal muscle and eyes. In the normal state the left vestibule tends to deviate eyes to the right and the right vestibule deviates eyes to the left. With the normal tone both effects abolish and the position of eyes remains straight ahead. When the left vestibule is destroyed, the normal tone which is exerted by the right pushes the eyes to the left side. This is corrected to the central position with a quick movement and nystagmus to the right side appears. But when the left vestibule is hyperactive the eyes are pushed to the right side.

In vestibular nystagmus the pathway of nerve impulses runs from the vestibular nerve to the vestibular nuclei in the brain stem, and the fibres which pass in the medial longitudinal fasciculus and in the reticular formation (FIG.5.208) are responsible for slow component discharge and go to the nuclei of ocular muscles. The fibres of slow component discharge relay impulses to high threshold reticular neurones. As far as their threshold is achieved the neurones fire off to produce the quick component discharge. At the same time these reticular neurones fire inhibitory neurones in

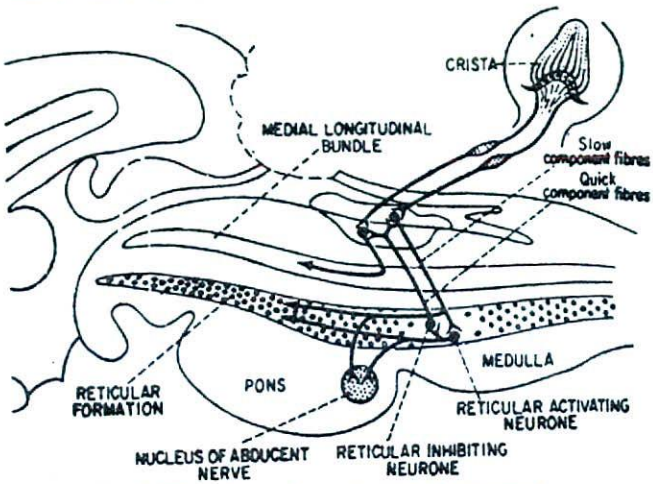


FIG.5.208.It shows the mechanism of nystagmus.

the brain stem reticular formation, which cut off a slow component discharge. So long as threshold of the neurones is reached again the high threshold reticular neurones rest and the cycle is repeated. Destruction of the inhibitor neurone does not produce any opposition in the pathway of nerve impulses in the medial longitudinal bundle, which by-pass the brain stem reticular formation resulting a conjugate deviation of the eyes.

The vestibular centres cannot control alone nystagmus. If the dorsolateral area of the diencephalon, medial to the lateral geniculate body, is stimulated, horizontal nystagmus with a quick component to the opposite side occurs. Direct stimulation of the vestibular nuclei produces a horizontal nystagmus at the same side. When the nystagmogenic areas of the vestibule and diencephalon are stimulated at the same time, the effects cancel each other out. But when the stimulations are crossed, there is an additive effect. Thus stimulation of the diencephalic nystagmogenic area causes contralateral nystagmus, whereas stimulation of the vestibular nystagmogenic area causes ipsilateral nystagmus (FIG. 5.209).

Excessive stimulation of the semicircular canals, particularly if the rotational movement is about a horizontal axis, commonly shows drowsiness, pallor, vertigo, salivation, nausea and vomiting feature of sea-sickness. There are unpleasant sensations from a conflict of sensory information.

Since the medial vestibular nucleus is very closely situated to the dorsal vagal nucleus, there is a considerable degree of interconnection between them. When the inhibitory influence is withdrawn from the vestibular

system the increased neural activity overflows to some cells in the dorsal vagal nucleus causing motion sickness. So the vagal stimulation causes headache, pallor, perspiration, nausea and vomiting of the motion sickness.

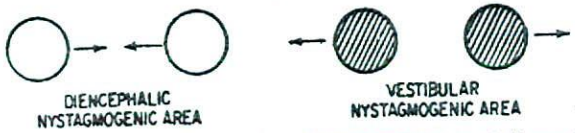


FIG.5.209. Diagrammatic representation of the manifestation of diencephalic and vestibular nystagmogenic areas.

An emotionally labile men cannot contain much sensory incongruity and cannot lift the inhibitory influence on the vestibular system earlier than others, they are more prone to motion sickness.

Functions. Semicircular canals give information about the *direction, degree and the plane of movement of the head* (kinetic or dynamic equilibrium). In man the semicircular canals can be stimulated by *angular acceleration.* This angular acceleration in man can be accomplished by seating the subject on a rotating chair (Bárány's chair)—producing *vertigo, nausea* and *nystagmus*. Besides this, the semicircular canal is also stimulated by (*a*) introducing cold or warm water into the ear, (*b*) circuit of a direct current through the labyrinth, and (*c*) mechanical stimuli through compression or decompression of air. Each functional pair gives information about its own plane. For instance, (1) right anterior and left posterior canals inform about the right oblique plane; (2) left anterior and right posterior about the left oblique plane; (3) two lateral canals inform about the horizontal plane. If movement be complex, more than one pair will come into action.

Coriolis effects. Coriolis effect is the specific type of angular acceleration that causes major motion sickness in spacecraft due to rotation of the earth deflecting a moving mass from a north or south path. This effect is generally observed when one set of semicircular canals has equilibrated to a constant angular velocity and a head motion is made in a different plane.

THE OTOLITHIC ORGAN

Anatomy. It consists of **saccule** and **utricle.**

Histology. Consists of same three coats as the semicircular canals. A sense organ (*neuroepithelium*), corresponding to crista, is present both in saccule and utricle, called the **macula.** The macular epithelium is same as that of the crista (FIGS.5.206& 5.210). The additional feature here is the presence of small **calcareous granules** (**otoconia** or **otolith**) embedded in the otolithic membrane. Here the cupola is replaced by the otolithic membrane which is also a gelatinous mass. When the head is in the erect position, the macula of the utricle remains in the horizontal plane with the hairs projecting upwards and the otoliths passively resting on the hairs (FIG.5.211C). The macula of the saccule, on the other hand, lies in the vertical plane, the hairs projecting horizontally outwards and the otoliths hanging down vertically on the outer side.

Mode of action. *The otolithic organs act as stretch receptors.* **Gravity** *acts as the stimulus.* When the otoliths hang down vertically, they exert a pulling action on the hairs and produce the maximum stimulation(FIG. 5.211A) When the otoliths passively rest upon the hairs, the stimulation is minimum(FIG.5.211C). Displacement of hairs in lateral directions or sideways

induces an intermediate type of stimulation (FIG.5.211B). Consequently, when the head is tilted on the left side, the otoliths of the left saccule are hanging downwards producing the maximum stimulation. While the oto-

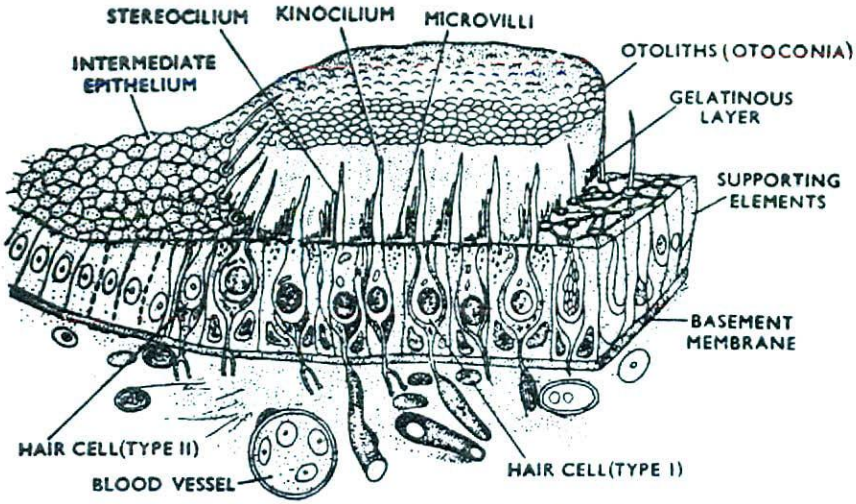


FIG.5.210. Histological representation of a macula (*after Carlos Eyzaguirre*)

liths of the right saccule are simply resting on the epithelium, causing the minimum stimulation. This difference of stimulation of the saccules on two sides gives conscious information about the position of the head in the

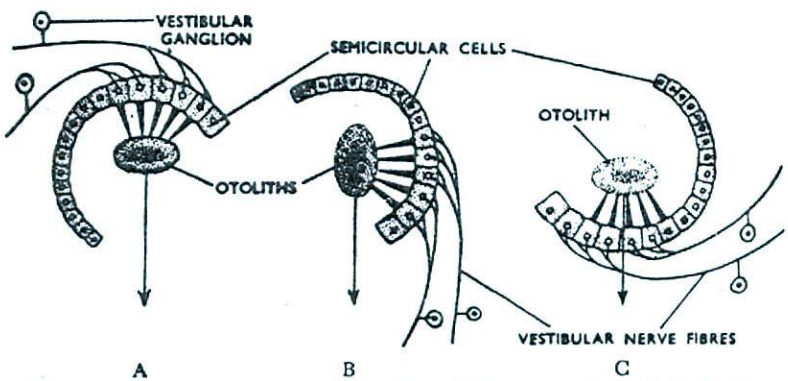


FIG.5 211. Schematic representation of the effects of different positions of the head on the otolithic organs. A = Otolith hanging vertically from the hairs (*maximum receptor stimulation*), B = Otolith pulling sideways on the hairs (*intermediate receptor stimulation*), C = Otolith pressing down on the hairs (*minimum receptor stimulation*) (*after Carlos Eyzaguirre*).

lateral plane Similarly, the utricular maculae are stimulated by antero-posterior movement of the head and give information about the position of the head in the antero-posterior plane (FIG. 5.211).

Functions. The **otolithic organs** *give information about the static position of the head* (static equilibrium) and not of movements. The **saccules** *give*

information regarding the position of the head in the lateral plane, while **utricles, in** *the antero-posterior plane.* With all its probability, otolithic organs are concerned with normal position of the head and with *linear acceleration.*

Unilateral extirpation of the labyrinths in lower animals produces derangements in postural mechanism and causes nystagmus, skew deviation of the eyes, alteration of the position of the head, spiral rotation of the trunk, flexion of the limbs towards the side of the lesion and extension of the limbs of the opposite side of the lesion. The animal comes at rest with the operated side down. In man a section of one vestibular nerve makes a temporary disturbance of posture and gait. This is at a minimum if the head is held steady because the gaze is also steady and external objects seem to be stationary. However, if side-to-side eye movements are required, as in crossing a street, vision is blurred and the gait appears to be unsteady. This may be caused by unilateral (i.e., asymmetrical) labyrinthine information reaching the brain. After some time these disorders disappear and the gait is maintained by the information coming from visual and muscle-joint receptors.

After **bilateral extirpation of the labyrinths** in lower animals there is a very unsteady posture with great loss of muscle tone and ataxia. The animals cannot stand, cannot orient itself under water and the birds are unable to fly. But in a higher animal the unsteady posture soon disappears as the animal learns to compensate for its disability by using its eyes and by proprioceptive reflexes. If the animal be blindfolded, postural unsteadiness returns. These disturbances of posture produced in man by bilateral destruction of the labyrinth are after some time compensated by visual righting and proprioceptive reflexes to a large extent but the deficit can be shown by tilting him suddenly. No compensatory reactions are observed. The labyrinth is concerned in keeping the visual axes steady, in spite of head movements, so that images of external objects are fixed (or stabilised) on the retina. For instance, when such a patient is roaming or is being wheeled across rough ground his vision is jumbled.

Oculogravic illusion (FIG. 5.212). Gravity acts on the otolithic system but if any other linear force acts, then the resultant of the forces acts on the otolithic system causing an illusion of the pilot of a high-speed fighter plane. In a high-speed plane, linear acceleration causes a posterior shearing force on the utricular maculae of the pilot when such a plane takes off. The resultant between the deceleration and constant downward gravity vector gives the pilot an impression that the plane is 'nose up' when, it is, in reality, flying straight. If the pilot flies according to his sensation and does not believe his instrument then the plane will touch the ground causing possible crash. This is the *oculogravic illusion.*

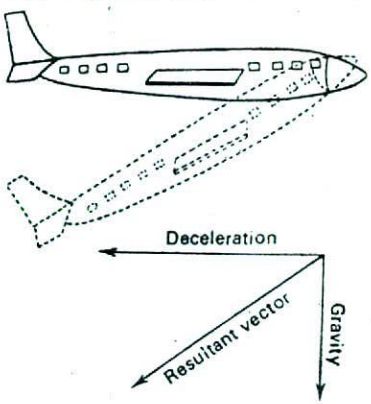


FIG. 5.212. It shows the oculogravic illusion.

In space flight due to weightlessness, gravity vector fails to act on the utricle and the astronaut does not feel which is 'up' and which is 'down'.

PATH OF VESTIBULAR IMPULSES

Vestibular impulses arise from the **cristae** of the semicircular canals and **maculae** of the saccules and utricles. They are carried by the dendrites of the nerve cells in the ganglion of Scarpa (*first neurone*). The axons of these cells form the vestibular division of the eighth cranial nerve. The nerve enters the central nervous system in the lower border of pons and terminates in the following ways (FIG. 5.213).

(*a*) Some fibres enter the cerebellum on the same side through the inferior peduncle, relay in the cerebellar nuclei and end in the cerebellar cortex.

(*b*) The remaining fibres terminate in the **vestibular nuclei.** The vestibular nuclei can be subdivided into four. (*i*) The *medial vestibular nucleus* is the largest and is situated in the vestibular area of the floor of the IV ventricle, crossed dorsally by the striae medullares. It extends upwards from the medulla into the tegmentum of the pons: (*ii*) The *inferior vestibular nucleus* is placed between the inferior cerebellar peduncle and medial vestibular nucleus and extends from the level of the rostral limit of the nucleus gracilis to the pontine-medullary junction. (*iii*) The *lateral vestibular nucleus* (of **Deiters**) is situated ventrolateral to the

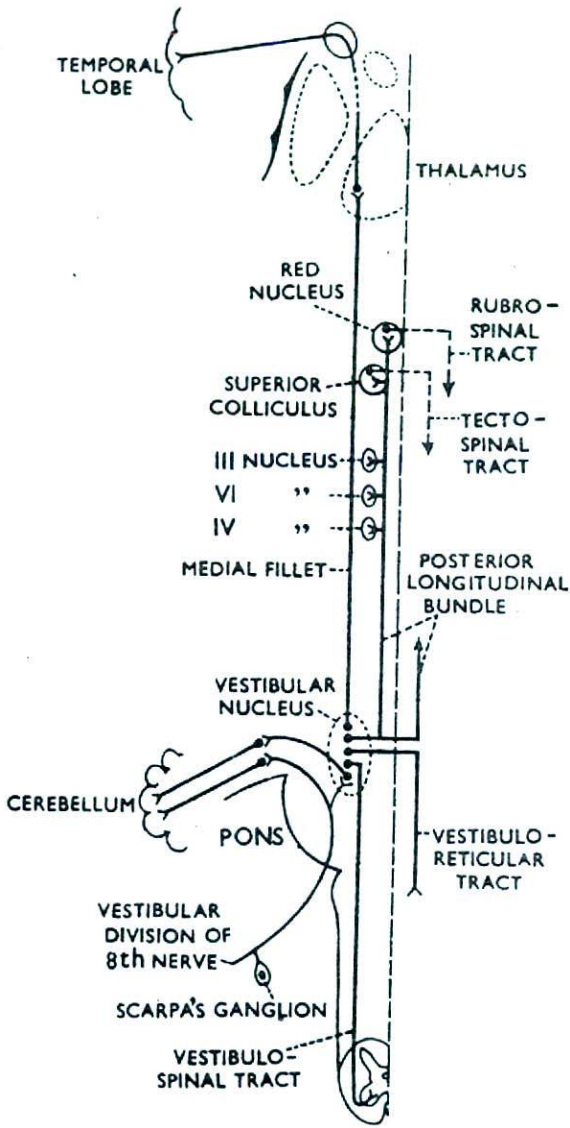


FIG. 5.213. Path of vestibular impulses.

upper part of the medial vestibular nucleus. (*iv*) The *superior vestibular nucleus* (of **Bechterew**) is small and lies above the medial and lateral vestibular nuclei. It extends higher into the pons than the other nuclei. From here the *second neurones* arise and proceed as follows:

1. **Vestibulo-ocular tract.** Some fibres (chiefly from Deiters' nucleus) constitute the *vestibulo-ocular tract.* They enter the posterior longitudinal bundles of both sides and end round the third, sixth and fourth nuclei. These fibres are concerned with the reflex movements of the eyeballs in response to vestibular impulses. A few fibres of this bundle end in the red nucleus and also in the superior colliculus of the same side.

2. **Vestibulocerebellar tract.** Some fibres enter the cerebellum through the inferior cerebellar peduncle mainly to the flocculonodular lobe of the same side and also to the fastigial nucleus of the same side (FIG. 5.214).

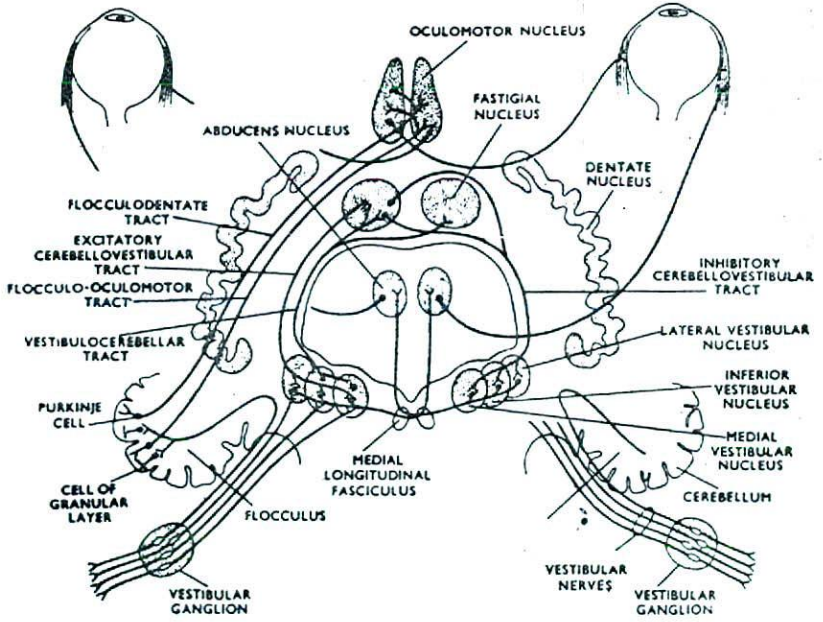


FIG. 5.214. Schematic representation of the connections between the vestibular nuclei and the cerebellum.

3. **Vestibuloreticular tract.** Some fibres end in the bulbar nuclei in the formatio-reticularis.

4. **Vestibulocortical fibres.** Some fibres (chiefly from the principal nucleus) enter the medial fillet and end in the thalamus. Here, the *third neurones* arise, pass with auditory fibres through the posterior limb of internal capsule and end in the temporal cortex. These fibres carry conscious vestibular sensations.

5. **Vestibulospinal tract** (from Deiters' nucleus) [*vide* pages 5-134–5-136].

The vestibular impulses therefore: (*a*) give conscious sensations regarding the position and movements of the head, (*b*) produce reflex ocular movements, (*c*) control tone, posture and equilibrium, (*d*) guide cerebellum and probably cerebrum.

Habituation. It is a process by which normal subjects adapt to complex new stimuli. With repeated exposure to vestibular stimulation, a number of individuals can develop relative insensitivity. Astronauts use to do long periods of training on centrifuges and in weightless states due to development of habituation and a depression of sickness and giddiness.

The vestibular system can perform some kind of autoregulation which allows the CNS to perceive facts that are essential to the organism and cancel out admittance to repetitive, irrelevant or inconsequential information.

CEREBRUM

Evolution. The cerebral hemispheres have developed from the roof of the forebrain. In the lowest vertebrates, where smell is the only special sense, cerebrum consists of the olfactory lobes only. As evolution proceeded, other varieties of special senses gradually developed. The crude sensory and motor functions, hitherto carried out clumsily by the thalamus and corpus striatum respectively, were more finely organised and transferred to a large extent, to the cerebral cortex. To deal with this vast stream of sensory and motor impulses, the cerebrum had to undergo a proportional development on all sides. It is to the evolution of this part of the nervous system that the superiority of the human beings over the lower animals is due.

Anatomy. Cerebrum consists of two symmetrical hemispheres, separated by a deep median furrow and connected by a broad band of commissural fibres—the *corpus callosum*. The total surface area of adult cortex is about 2200 sq. cm, and is nearly three times the inner surface of the skull. Owing to this mechanical discrepancy, the cortex becomes folded upon itself producing fissures and convolutions.

Each hemisphere has *five main lobes* and *four main fissures*. The **lobes** are: (1) **frontal** (anterior), (2) **parietal** (middle top), (3) **occipital** (posterior), (4) **temporal** (below parietal), (5) **limbic area** (at the base) (Figs. 5.215 & 5.216). The **fissures** are: (1) **central sulcus** or **Rolandic fissure** (between 1 and 2), (2) **parieto-occipital** (between 2 and 3), (3) **Sylvian fissure** (between 2 and 4), (4) **callosomarginal fissure** (between 4 and 5). *Frontal lobe* has four gyri—*precentral* (vertical), *superior*, *middle* and *inferior* (all three—

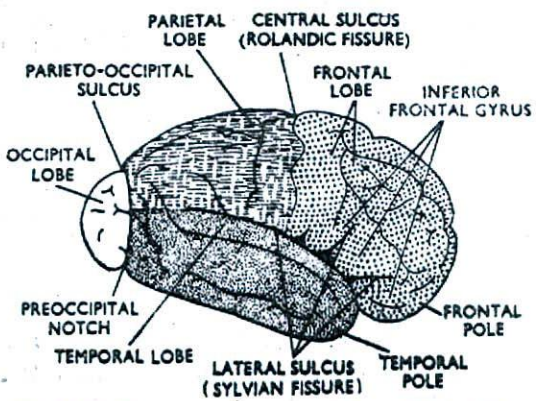


Fig. 5.215. Diagrammatic representation of the lateral surface of right cerebral hemisphere showing lobes of the brain.

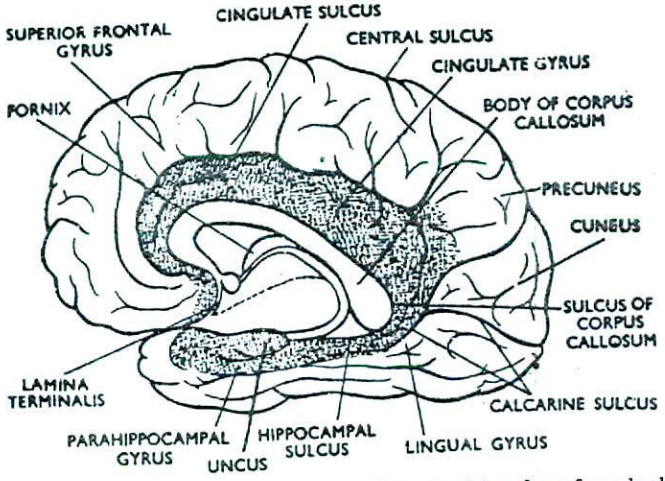


Fig. 5.216. Diagrammatic representation of the medial surface of cerebral hemisphere showing limbic lobe (shaded part) which encircles the upper brain stem.

horizontal). *Temporal lobe* has three—*superior*, *middle* and *inferior*—all horizontal (Fig. 5.217).

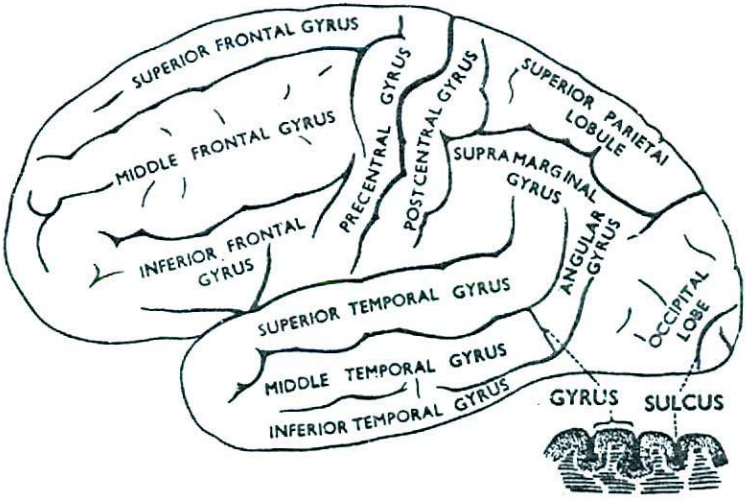


Fig. 5.217. The main gyri and sulci of the cerebral hemisphere.

Gray matter (Cortex). It forms the surface layer, thickest (4·5 mm) at the precentral gyrus and thinnest (1·3 mm) at the frontal and occipital poles. Average—3·5 mm on the surface, 3 mm at the base and 2·7 mm medially. In the sulci the thickness is half that on the surface. About two-

thirds of gray area remain hidden in the sulci and one-third exposed on the surface. It is composed of *nerve cells*, *nerve fibres* and *neuroglia*.

Roughly **five** types of nerve cells are: (1) **Pyramidal** which look like forms of pyramids or isosceles triangles and possess large vesicular nuclei and distinct Nissl bodies. The heights of smaller and of larger pyramidal neurones are 10–12 μ and 45–50 μ respectively, but in the motor area of the precentral gyrus large pyramidal cells of Betz, generally, may be more than 100 μ in height. (2) **Small stellate** or **granular** which are triangular or polygonal in size of 4–8 μ and have dark-staining nuclei and scanty cytoplasm. Resembling pyramidal cells, other **larger stellate cells** are known as **stellate pyramidal cells** or **star pyramidal cells.** (3) **Fusiform** or **spindle** which are generally placed vertical to the cortical surface with their long axes and are mainly found in the deepest cortical layer. (4) **Horizontal cells of Cajal** which look like pear-shaped or small fusiform cells and are found in the most peripheral layer. (5) **Cells of Martinotti** or **cells with ascending axons** which are small triangular or polygonal and present in all layers generally.

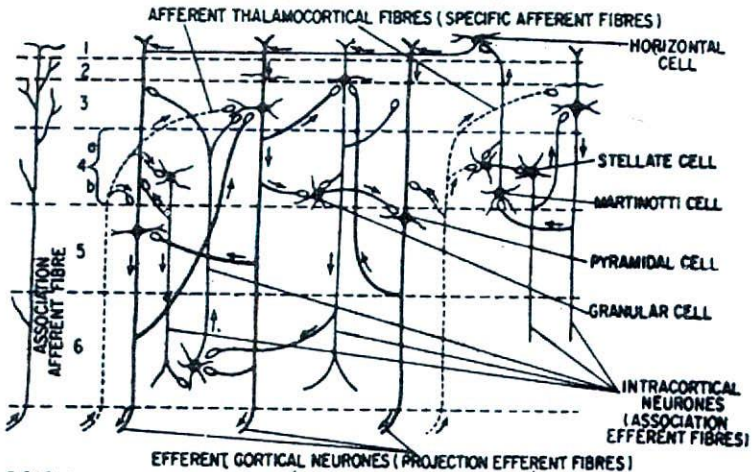


FIG. 5.218. Schematic representation of a few intracortical fibres showing synaptic junctions with loop system and termination of association afferent cortical fibres within six layers of cerebral cortex.

Functionally also five types: (1) Cells whose axons come out from the base of the cells, descend toward the medullary substance and terminate in the deepest layer or enter the white matter as *projection or association fibres*. (2) Cells whose (*a*) shorter axons ramify close to the cell body (Golgi type II) and (*b*) longer axons enter the medullary substance. (3) Cells whose axons emerge from middle or lower parts of the cell body and enter the white matter as *projection or association fibres*. (4) Cells whose axons pass horizontally for a considerable distance and arborise in the same layer. (5) Cells whose axons, facing toward the cortical surface, extend a variable distance and *some of them* arborise in that layer and the *rest* project collaterals to a number of layers.

However, *pyramidal*, *fusiform* and *large stellate cells* possess descending axons which leave the cortex as *projection and subcortical association fibres* and

the entering afferent projection and association fibres terminate within the cortex. But *horizontal cells of Cajal, cells of Martinotti* and *Golgi type II granular cells* have *intracortical connections*. The terminal branches of the *afferent projection and association fibres, axons of horizontal and granular cells, terminal branches of collateral fibres* from pyramidal and fusiform cells have tangential fibres which run horizontally to the cortical surface (FIG. 5.218).

White matter. Remains under the gray matter. Composed of three groups of medullated fibres: (1) **Projection fibres,** connecting cerebrum with extracortical areas. **Two varieties:** (*a*) **Afferent**—thalamocortical, auditory radiation, optic radiation, cerebellocerebral, etc. (*b*) **Efferent**—pyramidal, frontopontine, corticonuclear, temporopontine, etc. (2) **Association (arcuate) fibres,** connect different parts of same hemisphere. They are of two kinds: (*i*) *short association fibres* which connect adjacent gyri to one another, and (*ii*) *long association fibres* which connect more widely separated gyri to one another (FIG. 5.219).(3) **Commissural fibres,** unite the two hemispheres: (*a*) Corpus callosum, (*b*) Anterior commissure—between two temporal lobes, (*c*) Hippocampal commissure, between two hippocampal gyri.

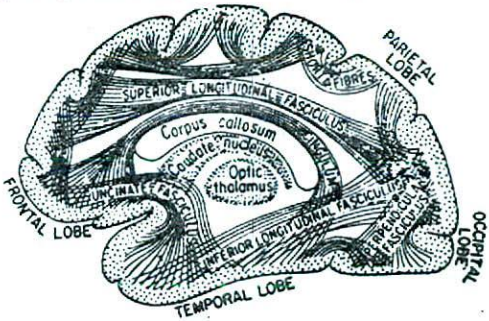


FIG. 5.219. It shows the principal system of association fibres in the cerebrum. Gray matter is stippled.

STRUCTURE OF THE CEREBRAL CORTEX AND FUNCTIONS OF ITS DIFFERENT LAYERS

Histologically, cortex has three divisions: (1) **Allocortex**—hilus of the cerebral hemisphere, comprising the olfactory area only. (2) **Isocortex (neocortex)**—cortical tissue of remaining non-limbic regions of the cerebral hemisphere. (3) Between the allocortex and the rest of the cerebral hemisphere (isocortex) the **juxtallocortex** or **mesocortex** (cingulate gyrus) is present. *Allocortex* is primitive, having altogether a different structure. Lamination is imperfect here. For instance, in the hippocampal region, only three layers—outer molecular, external pyramidal and innermost fusiform layers. Other layers found in isocortex are not present here.

Isocortex (neocortex) has six fundamental layers of cells and fibres, with characteristic regional peculiarities. The fibres are arranged both *in*

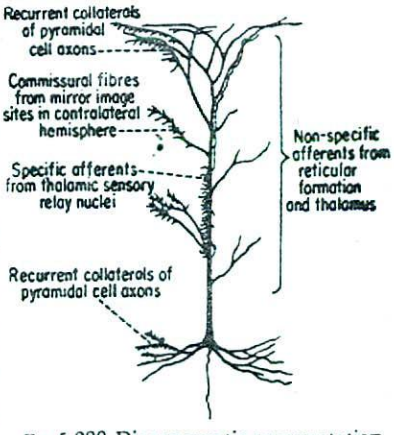


FIG. 5.220. Diagrammatic representation of cortical pyramidal cell along with distribution of presynaptic terminals (*after Chew & Leiman*).

transverse as well as in longitudinal bands. The afferent projection fibres penetrate the deeper layers as *longitudinal bundles*, reaching up to the second layer and giving transverse branches which make synapses with other motor or internuncial neurones at different levels (FIG. 5.220). All pyramidal and possibly other types of cells give rise to three sets of fibres. (1) The *apical dendrite* passing upwards and giving transverse collaterals. (2) The *basal axon* passing downwards forming efferent projection fibres (may also have transverse branches). (3) A number of *lateral dendrites* arising from the sides of the cells and passing transversely. *These tangential fibres form transverse bands.*

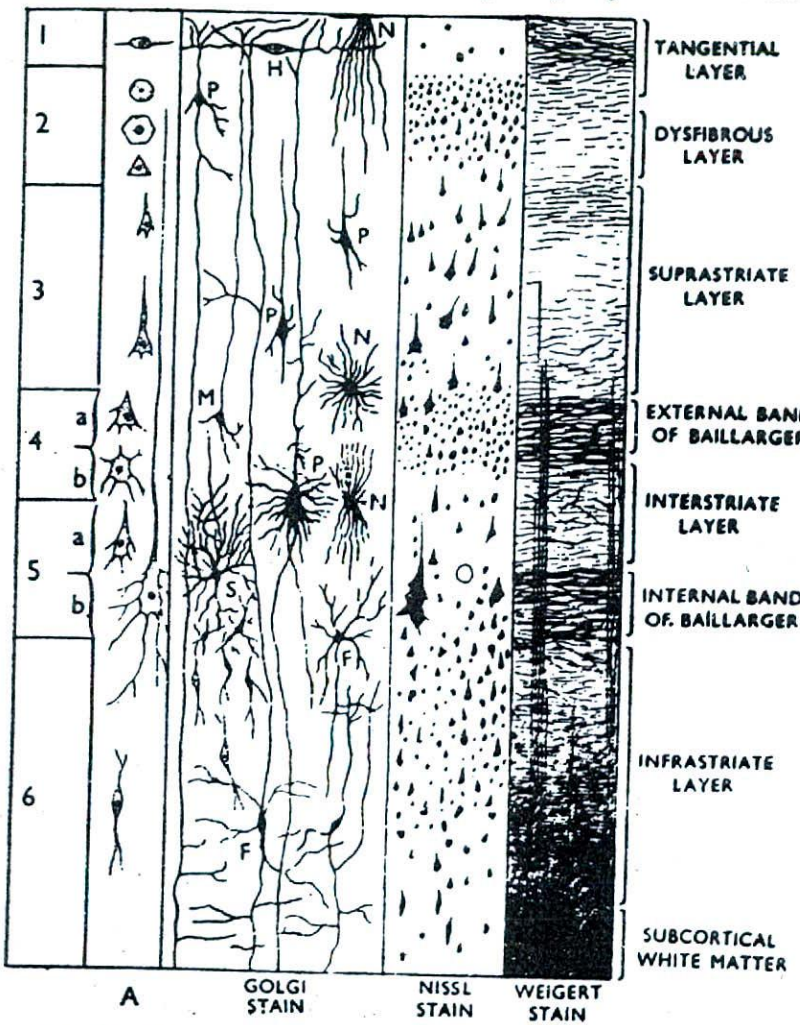


FIG. 5.221. Schematic representation of six layers of cells and arrangement of fibres of the human cerebral cortex.
A = Diagrammatic representation of cells.

From this arrangement, the following conclusions may be drawn: (1) The cells in the different layers remain united in vertical chains which possibly act as compound functional units. (2) The afferent projection fibres, with the help of transverse collaterals, form synaptic connections with motor (or intermediate) cells at various levels and form the so-called **elementary cortical unit.** Through this unit, the afferent impulse is passed on to the efferent side. (3) Since the apical process of the pyramidal cell may pierce several layers, the same afferent impulse may reach a particular pyramidal cell repeatedly from different layers.

From outside inwards the six layers (FIG. 5.221) are as follows:

1. **Plexiform layer** or **Molecular layer**—few cells, many fibres. **Cells**—(*a*) *neuroglia*, (*b*) *horizontal cells of Cajal.* **Fibres**—form a prominent transverse band.

2. **External granular layer**—many small cells, few fibres. **Cells**—(*a*) *Granular cells*—round, triangular or polygonal. (*b*) *Small pyramidal cells.*

3. **External pyramidal layer**—thick layer of *medium pyramidal cells.* Cell size increases inwards.

4. **Internal granular layer**—two parts—**4a** (outer)—(1) *Star pyramidal cells*, (2) *Thick transverse band*—**outer line of Baillarger.** **4b** (inner)—*irregular stellate cells.*

5. **Internal pyramidal layer**—two parts—(1) (*a*) **5a** (outer)—*small pyramidal cells*, (*b*) **5b** (inner)—*large pyramidal cells* (*Betz cells*). (2) **Inner line of Baillarger.**

6. **Fusiform cell layer**—thick layer of *spindle-shaped cells* arranged perpendicular to the surface. Fibres form thick meshwork.

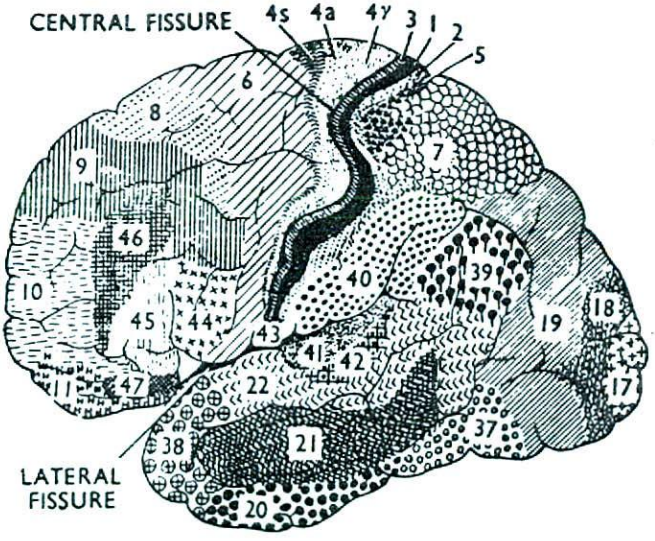


FIG. 5.222. Schematic subdivision of the medial surface of the cerebral hemisphere showing localisation of the areas according to Broadmann.

Regional peculiarities

1. **Excitomotor area** (area 4: (*i*) 4γ, (*ii*) 4a, (*iii*) 4s—precentral gyrus)—(*a*) Both the granular layers are thin. (*b*) Characteristic layer of Betz cells. (*c*) Origin of pyramidal tract.

2. **Premotor area** (areas 6 and 8—frontal lobe)—(*a*) Betz cells absent. (*b*) Intercommunicates with area 4. (*c*) Efferent projection fibres arise and end in pontine nuclei (frontopontine), corpus striatum, red nucleus, superior colliculus and other extrapyramidal nuclei.

3. **Visual area** (Occipital lobe—areas 17 and 18). (*a*) Granular layers prominent. (*b*) Outer pyramidal layer indistinct. (*c*) A few giant pyramidal cells of Meynert in the fifth layer (origin of association and projection fibres). (*d*) The outer line of Baillarger is very prominent and called the *line of Gennari*. (*e*) Inner line of Baillarger is indistinct.

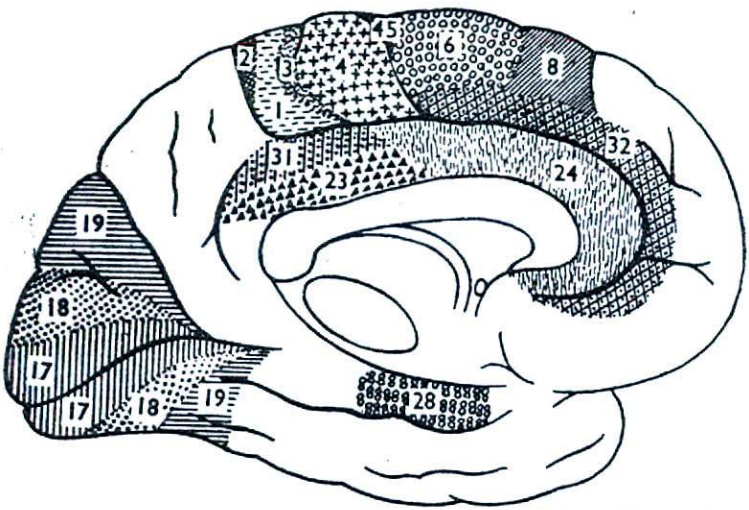


FIG. 5.223. Schematic subdivision of the medial surface of the left cerebral hemisphere showing some of the cytoarchitectural areas.

4. **Somaesthetic area** (Parietal lobe—areas 3, 1, 2 and 5, 7). (*a*) Granular layers thicker and denser. (*b*) Pyramidal cells smaller. (*c*) Receives thalamocortical fibres (general senses).

5. **Auditory area** (Temporal lobe—areas 41, 42, 22, 21, 20). (*a*) Granular layers prominent. (*b*) Fourth layer rich in pyramidal and stellate cells, from which (*c*) temporopontine fibres arise. (*d*) Receives auditory (from external geniculate body) and vestibular afferent projection fibres. (*e*) Gives fibres to external geniculate body and inferior colliculus. (*f*) Outer line of Baillarger is prominent and is called the *line of Kaes*.

According to regional peculiarities Economo divides isocortex into *five types*. Types 2, 3 and 4—differ only in detail. Types 1 and 5 have marked fundamental distinctions. Brief details are given below:

Type 2—**Frontal type** (Anterior two-thirds of frontal lobe, superior

parietal lobule and part of temporal). Here, granular cells are triangular.

Type 3—**Parietal type** (Parietal lobe; junctional region between parietal, temporal and occipital lobes). Here, the two granular layers are thick and dense, granular cells are round and pyramidal cells are smaller, thinner and more numerous.

Type 4—**Polar type** (Frontal and Occipital poles). Gray matter thinnest. All layers thinner but densely packed.

Type 1—**Agranular cortex** (Motor areas—4, 6, 8). Granular cells replaced by pyramidal cells. Betz cells in area 4.

Type 5—**Granular cortex** (Sensory areas including special senses). Pyramidal cells replaced mostly by granular cells in layers 3 and 5.

Functions of different layers of the cerebral cortex

Pyramidal cell of the motor cortex receives impulses from many cells which convey impulses through synaptic connections. Afferent stimuli are coming from other subcortical or neighbouring cortical cells (FIG. 5.224). shown by arrows) or from collaterals of the large pyramidal cell itself.

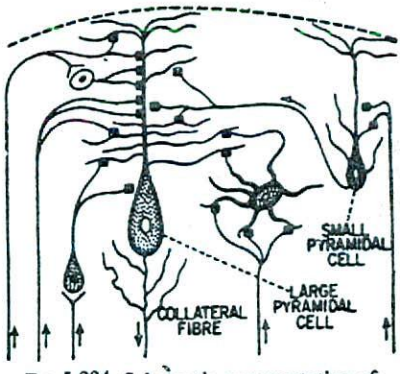


FIG. 5.224. Schematic representation of the pathways of afferent stimuli.

1. The inner layers are concerned with organic and instinctive faculties. Little difference is seen here between man, monkey and dog. The inner layers are believed to be the fundamental layers from which the outer layers grow. This is seen both during embryological as well as in evolutional development.

2. The middle pyramidal layers are concerned with the reception of afferent impulses and their conversion into efferent.

3. The granular layers are sensory and associative in function.

4. The outer layers are concerned with intellectual and associative faculties. Various forms of amentia (poor mental development) are associated with subnormal development of outer layers. *Atrophy* of these layers leads to dementia (mental degeneration).

Localisation of brain function

The result of various experiments on animals and close observation of effects of electrical stimulation of the cerebral cortex on the human being and clinical results of cerebral disease, physiologists have been able to localise certain areas in the brain which control motor, sensory and other activities (FIG. 5.225). In any case, however, the control of a function is not limited to a single centre. Because all mental processes involve the discharge of nervous energy from one centre to another. Change in the nervous activity of any part alters the excitability of the whole part. No one area acts alone to govern a particular function. According to

Herrick "*such areas are merely nodal points in an exceedingly complex system of neurones which must act as a whole in order to perform any function whatsoever.*"

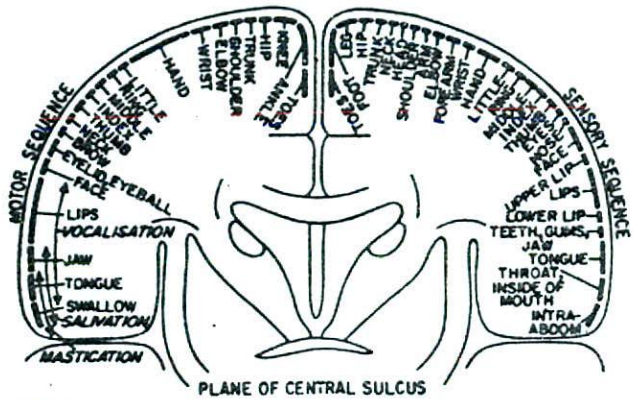


FIG. 5.225. Rasmussen and Penfield's diagram of localisation in motor and sensory cortex. The lengths of solid bars depict an estimate of average relative cortical areas from which corresponding responses are elicited.

METHODS OF LOCALISATION OF FUNCTIONS IN THE CEREBRAL CORTEX

Since cortical neurones freely intercommunicate and since injury to any part of the cortex disturbs the functions of its other parts, it was held before that brain worked as a single organ. But later investigations point out that there are particular areas in cortex serving specific functions. These special areas subserving special functions are called **centres.** From these facts cerebrum should not be regarded as a single organ but as a co-ordinated aggregate of many component organs—something like a 'union of states' in which the individual members are autonomous but interdependent—all within the framework of a common law for a common purpose. More detailed analysis points out that even inside a centre there are special areas where functions vary in detail. Hence, for convenience of description and comparison, cortex has been mapped out into different areas each bearing a definite number, such as 3, 1, 2, etc. The following methods are commonly adopted for localising cerebral centres.

1. **Histological study.** Variety and distribution of nerve cells (*cyto-architectonics**) (FIGS. 5.222 & 5.223) and fibres (*myeloarchitectonics*).

2. **Study of myelination** (Flechsig). Fibres in all parts of cortex do not myelinate at the same time. A regular order is seen. Myelination takes place first in the sensory areas (three months before birth), then in the motor areas (may be several months after birth), and lastly in the association areas, where it may proceed up to 40 years.

3. **Study of the origin and termination of the motor and sensory tracts.** From the origin and terminations of motor and sensory tracts the functions of the related portions of the cortex may be known.

4. **Effects of experimental stimulation.** Electrical, chemical (strychnine, etc.), etc.

* Mapping of different areas according to the cytological characteristics as observed through histological studies is called **cytoarchitectonics.**

5. **Effects of removal of different regions.**
6. **Clinical effects** of irritative or degenerative lesions.
7. **Establishment and abolition of conditioned reflex.** At first, a conditioned reflex is established, say, with a particular sound as the stimulus. If then removal of a particular cortical area abolishes the reflex, the area removed is obviously concerned with sound (i.e., hearing).

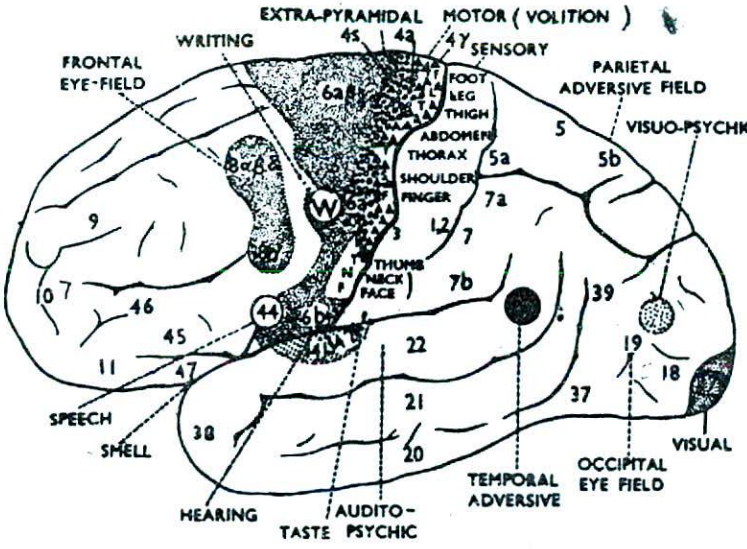


FIG. 5.226. The centres and areas in the left cerebral hemisphere.

8. **Electroencephalogram.** Like other cells, activity in the nerve cells is also attended with potential changes, which can be detected by **electroencephalograph.** If appropriate sensory stimuli be applied to peripheral parts (skin, muscles, taste, smell, vision, hearing, etc.), changes of electrical potential take place in the cortical centres concerned. In this way sensory areas can be mapped out (FIG. 5.226). [*Vide* Electroencephalography.]

AREAS AND CENTRES IN THE CEREBRAL CORTEX

With the help of above methods, nearly 200 areas have been mapped out in the cortex. There are certain areas which on stimulation abolish the resting cortical potentials. The areas are called **suppressor bands.** They have been described along with the different areas.

I. FRONTAL LOBE. It is subdivided into two main areas: (*a*) the precentral cortex, and (*b*) the prefrontal cortex.

Precentral cortex (areas 4, 6, 8, 44)

1. **Area 4 (4a, 4s, 4γ)** (Precentral motor area). **Situation**—anterior wall and lip of central sulcus (in apes also the precentral gyrus) and extends on to the medial surface of the hemisphere. **4a**—constitutes the larger area of precentral gyrus. **4s**—lies in front of the area 4a which is

functionally an inhibitory area. It helps in controlling the stretch and postural reflexes. Lesion of this area causes spasticity of muscles. Spasticity of muscles in hemiplegia is due to involvement of this area. **4γ**—which is situated posterior to 4a which contains giant pyramidal cells—Betz cells. (**Fig. 5.227**). **Function**—*Centre for volition.* Centres for the various parts of body are *arranged upside down*, viz., from above downwards—toes, foot, leg, thigh, abdomen, thorax, shoulder, arm, hand, fingers (5, 4, 3, 2), thumb, neck, face (ear, eyelids, nose, tongue, jaw, palate), larynx. This area (in apes but not in man) is interrupted by area 6aα which remains interposed between the centres for fingers and thumb.

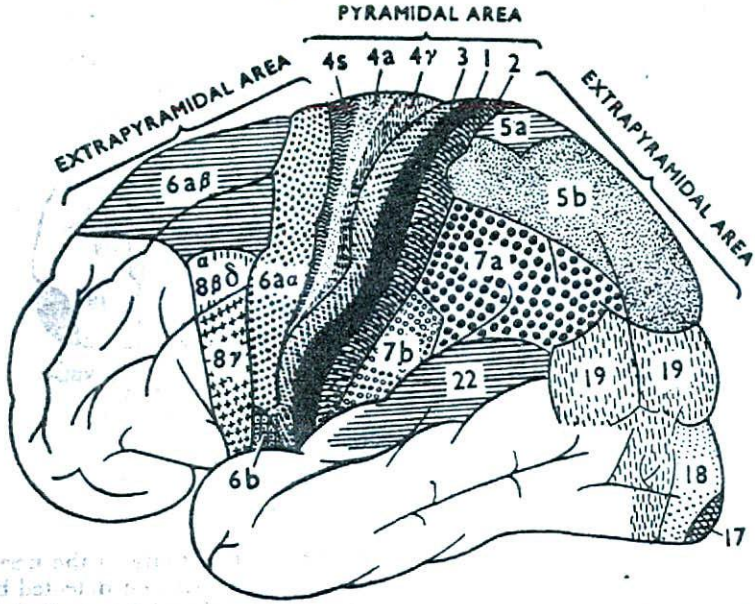


Fig. 5.227. Schematic representation of electrically excitable areas of the lateral surface of human brain showing pyramidal areas and extrapyramidal areas.

2. **Area 6** (Premotor area). **Situation**—in front of area 4. **Two parts**—the upper 6a and lower 6b.

6a—Subdivided into two parts—upper 6aβ, lower 6aα. The former is situated in the superior frontal and precentral gyri, the latter juts into the area 4 as mentioned above. Frontopontine and certain other efferent projection fibres arise from this area and control the extrapyramidal tracts. **Functions**—(*a*) *Frontal adversive field*—stimulation causes movements of eyes, head and body towards the opposite side. (*b*) *Extrapyramidal activity*—all functions attributed to the extrapyramidal tracts (*vide* page5-137). (*c*) **Writing centre**—Area 6aα (on the left side in right-handed people) is believed to contain the **centre for writing.**

6b—Situated below area 4 **Functions**—(*a*) *Controls complex movements* of jaws, tongue, pharynx, larynx, swallowing and also the activity of the respiratory muscles (electrical stimulation causes rhythmic movements of these parts and also respiratory changes like hiccup, grunting, etc.).

(*b*) *Extrapyramidal functions.* (*c*) **Speech centre**—On the left side (in the right-handed people) it contains Broca's area (areas 44 and 45), which is the **centre for speech.**

3. **Area 8** (Frontal eyefield). It is called the *frontal eyefield.* **Situated** in front of area 6aα. Two parts—upper 8αβδ in the middle frontal gyrus and lower 8γ in the inferior frontal gyrus. Corticobulbar (corticonuclear) fibres (*vide* page 5-128) arise from this area and end round the third, fourth and sixth nuclei on the opposite side. **Function**—Controls the conjugate movements of the eyeballs to the opposite side, opening and closing of the eyelids and sometimes dilatation of the pupils and lacrimation. Stimulation of this area in man causes conjugate deviation of the eyes and turning of the head to the opposite side. Bilateral lesion of this area in animal does not react to visual stimuli in normal manner.

Area 8s—Situated in front of area 6. **Function**—Inhibits resting cortical potential.

4. **Area 44.** It is situated in the region of the posterior part of the frontal operculum in the dominant hemisphere and is the motor area (Broca's area) for speech. If this area is stimulated in conscious subject then speech is abruptly arrested.

Prefrontal cortex (areas 9, 10, 11, 12, 32)

It is the remainder of the frontal lobe including the orbital gyri, medial frontal gyrus and area 32. This cortex is also known as *orbitofrontal cortex.* Broadmann divided this cortex into different areas—9, 10, 11, 12, 13 and 14. But Baily and von Bonin did not support this division.

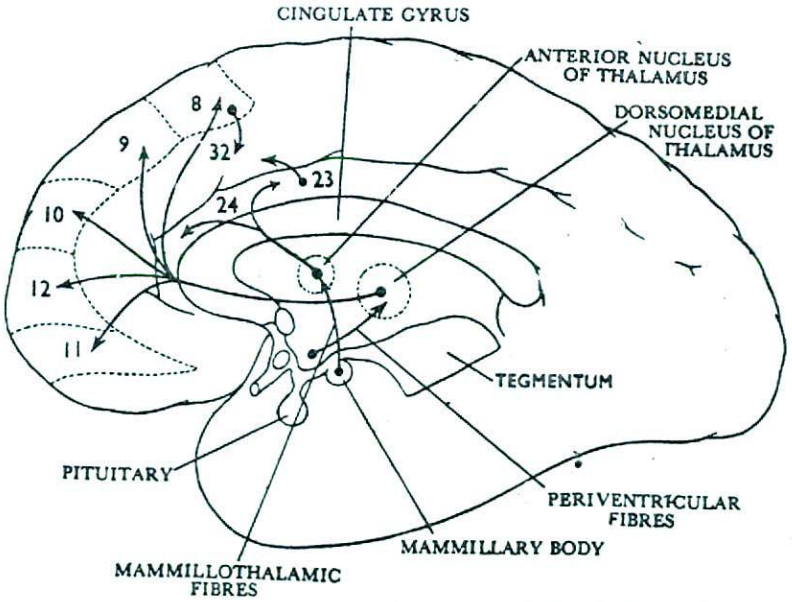


FIG. 5.228. Schematic representation of thalamicocortical projections on the premotor fields of the frontal lobe (*after Le Gross Clark,* 1948).

The prefrontal lobe of the cerebral cortex is the anterior part of the cerebrum. It remains anterior to areas 4, 6 and 8. Each lobe extends on to the medial surface of the hemisphere up to the anterior end of the corpus callosum and includes part of the **cingulate gyrus (area 24).**

Areas 9, 10, 11, 12. Situation—Anterior part of the frontal lobe. Areas 9 and 10—on the convexity and medial surface. Areas 11, 12—on the under surface. **Function**—*Seat of intelligence* (i.e., highly associative). Unresponsive to electrical stimulation, hence, called *silent area*. Bilateral removal leads to mental impairment. Hence, called **organ of mind.**

Connections of the prefrontal lobes

It has got extension subcortical and cortical connections.

(1) **Afferent**—(*a*) Anterior nucleus of the thalamus to cingulate gyrus (areas 23, 24, 29, 32). (*b*) Medial dorsal nucleus of the thalamus to areas

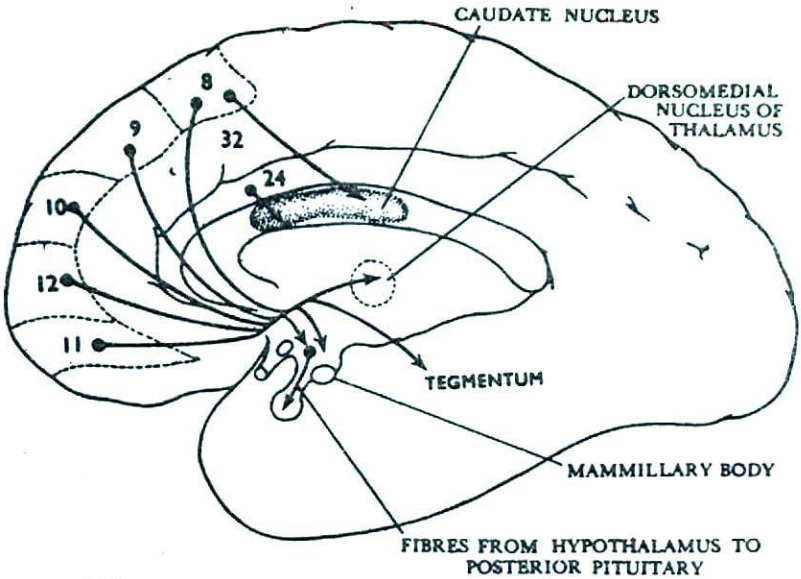


FIG. 5.229. Schematic representation of corticohypothalamic as well as cortico-thalamic projections showing efferent connections of the premotor area of the frontal lobe (*after La Gross Clark*, 1948).

8, 9, 10, 11, 12 (FIG. 5.228) and areas 44, 45, 46, 47. (2) **Efferent** (FIG. 5.229):—(*a*) From areas 9 and 10 to the ventral and medial dorsal nuclei of the thalamus. (*b*) From area 8 to the tegmentum (subthalamus) of the mid-brain. (*c*) From the areas 9 and 10 to the reticular formation in the tegmentum (subthalamus). (*d*) From area 10 to the pontine nuclei. (*e*) From areas 8s and 24s to the caudate nucleus. (*f*) From the hippocampal region to the mammillary body (hypothalamus). (3) **Connections between different lobes**—(*a*) Area 8 is connected with area 18 in the occipital lobe. (*b*) Areas 8s, 24s, 4s, 2s and 19s are connected with area 32. (*c*) Areas 44, 45, 46, 47 are connected with the visual and auditory areas in the occipital and temporal lobes respectively (FIG. 5.230).

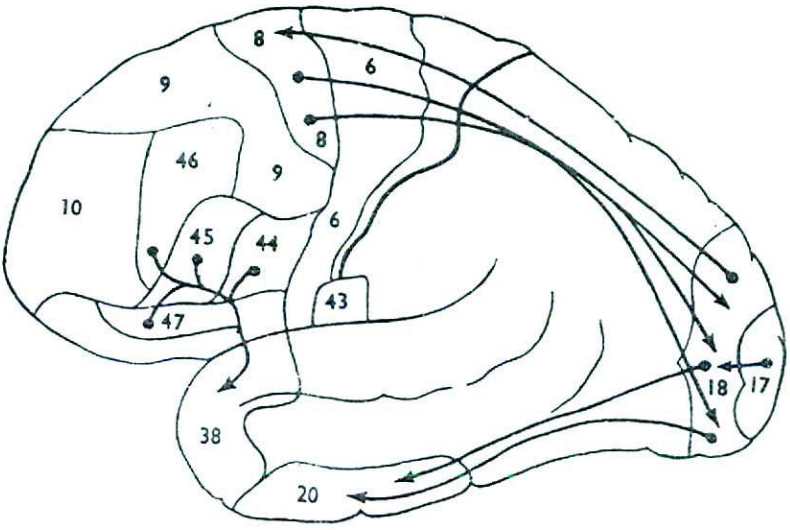


FIG. 5.230. Schematic representation of reciprocal connections of the frontal, occipital and temporal lobes through intracortical association bundles (*after Le Gross Clark*, 1948).

Functions of the prefrontal lobes

Most of the functions of the prefrontal lobes are closely associated with that of the functions of the ideomotor area or centre which is located in the supramarginal gyrus of the parietal lobe on the dominant side of the cerebral cortex.

The **ideomotor area** is under the inhibitory control of the prefrontal lobes. If the ideomotor area or centre is allowed to act independently, i.e., without the inhibitory control of the prefrontal lobes then there would have been responsed to every type of sensory impulses received. The prefrontal lobes discriminate the sensory impulses, correlate them with the stored impression and help in the final response through the ideomotor area or centre. The prefrontal lobes associate themselves with other lobes of the brain, viz., parietal, occipital and temporal lobes through the association fibres and act as planning organs. Prefrontal lobes help in complex intellectual activities, e.g., working-out mathematical problems, giving judgement, etc.

The prefrontal lobes are connected with the thalamus, hypothalamus, tegmentum (subthalamus), visual and auditory areas. The prefrontal lobes through their connections with hypothalamus and brain stem exert their influence on the autonomic nervous system. Alteration in heart rate, blood pressure and respiration occurs after stimulation of area 13.

Effects of removal of the prefrontal lobes

After removal of the prefrontal lobes in rhesus monkey following effects have been observed: The animal sits quietly with bowing of the head and remains apathetic. After few weeks the animal becomes hyperactive and restless. There are alteration in behaviour, impairment of

memory, loss of learning power, and a state of resembling **sham rage phenomenon** develops. After removal of the prefrontal lobes in *prefrontal lobe tumour* the effects have also been studied in human being. *Unilateral* removal of prefrontal lobes does not cause much alteration in mental processes but *bilateral* removal impairs moderate mental alteration. The chief manifestations are: (*a*) lack of self-control, (*b*) distractibility (difficulty of attention), (*c*) flight of irregular linkless ideas, (*d*) loss of memory, specially for the recent events, (*e*) lack of initiative, (*f*) alteration in social behaviour, loss of moral and social sense, (*g*) disturbed orientation of time and space, (*h*) failure to realise the seriousness of his own condition and a disproportionate sense of well-being (euphoria). Owing to these functions the prefrontal region is called the **organ of mind.** There will be no disturbance of voluntary movements if the excitomotor areas are not excised.

Other manifestations of prefrontal defects are (1) the tremor, (2) the disturbances in orienting the time and space, (3) the increased appetite, (4) the impaired control of the sphincter of the bladder and rectum.

Frontal lobe and the seat of intelligence

It is of general belief that this lobe is the seat of intelligence in animal and the centre or the organ of mind. But World War II has provided an immense scope of such studies in subject having traumatic prefrontal injuries. From systematic studies in such patients it has been observed that destruction of prefrontal region does not produce any notable deficit in intelligence. From extirpation studies it do not suggest that intelligence, memory, control of behaviour, etc., are solely or even predominantly dependent upon the prefrontal cortex. This area probably represents a region of relatively high associative and synthetic capability. This area is meant for mental processes related to *prediction*, forecasting or to any planned activities. Housewife having loss of this area may feel difficulties in planning a meal. Mental capacity is a function of whole of the cerebral cortex and not of a particular region.

II. PARIETAL LOBE (mostly **sensory** and **association** areas. Only slightly motor—*adversive*).

Sensory areas (Areas 3, 1 and 2)

SOMAESTHETIC AREA OR 'PRIMARY SENSORY' AREA OR SOMATIC SENSORY AREA (FIG. 5.231)

Areas 3, 1, 2. Situation—Posterior wall and lip of central sulcus and postcentral gyrus. **Functions**—Appreciation of general senses, such as touch, pain, heat, cold and kinaesthetic from the opposite side of the body. *The centres for the different parts of the body are arranged upside down in the same order as the motor centres in area* 4. The primary sensory area has been called by Woolsey as **somatic area I.** Recently, another sensory area has been found out which is called as **somatic area II.** The latter is more primitive of the two and receives crude sensation, whereas the former receives epicritic sensation. The motor centre of a particular part lies just in front of the sensory centre of the same part just like a mirror image. *Central sulcus seems to be a great dividing line between motor and sensory areas.* In the somaesthetic area the complete meaning of a particular sensation is understood, such as (*a*) appreciation of the size, shape, texture and weight of the objects—**stereognosis.** (*b*) Appreciation of the

relative intensity of the different stimuli. (*c*) Tactile localisation, tactile discrimination of two points, recognition of position and passive movements of the limbs—**spatial recognition.** Lesion of this area results in disturbances of these faculties and there will be astereognosis, loss of spatial recognition, appreciation of the relative intensity of the different stimuli.

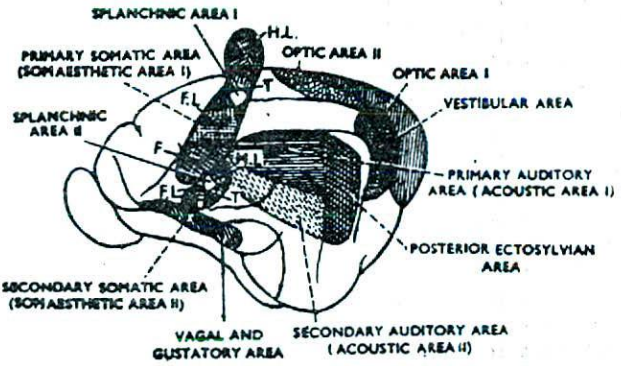


FIG. 5.231. Diagrammatic representation of the primary and secondary cortical sensory areas, primary and secondary auditory areas; visual areas; splanchnic areas, vestibular area, vagal and gustatory area and a portion of medial aspect of the brain shown above. Primary and secondary somatic areas indicating somatotropic representation of different portions of the body showing F=face area, T=trunk, FL=forelimb, HL=hindlimb.

Inferior part of the postcentral gyrus contains the **centre for taste** and **general sensations from tongue.** Lesion of the inferior part of the postcentral gyrus causes loss of taste and general sensations of the opposite half of the tongue.

Area 2s—Situated in the postcentral gyrus. **Function**—Inhibits resting cortical potential.

Association areas (Areas 5, 7)

1. **Area 5. Situation**—Superior parietal lobule. **Two parts**—5a (anterior), 5b (posterior). 5a is sensory association, included in the somaesthetic area. 5b is motor (described below).

2. **Area 7. Situation**—Supramarginal and angular gyri. Included in somaesthetic area. **Two parts**—7a (upper) and 7b (lower). **Function**—Sensory association.

In the somaesthetic area (3, 1, 2, 5, 7) not only the general senses are perceived, but their full associative meaning is interpreted.

Motor area (Adversive)

Area 5b (Parietal adversive field). Electrical stimulation causes movement of eyes, head, etc., to the opposite side. A similar adversive field is believed to be present in area 7a (angular gyrus).

III. TEMPORAL LOBE (mostly **sensory** and **association** areas, viz., Auditosensory and Auditopsychic areas. Only slightly motor—*adversive*).

Sensory area (Auditosensory)

Areas 41 and 42. Situation—Heschl's gyrus, mostly hidden in the Sylvian fissure. **Auditosensory area**—This area is grouped into **audito-**

sensory area I and **auditosensory area II.** In auditosensory area I the basal turn of the cochlea is projected anteriorly and the apical turn posteriorly, whereas in auditosensory area II the representation is quite reverse. **Function**—*Centre for hearing.* Here the pitch, loudness, quality, etc., of sounds are perceived (the auditory centre also includes a small adjoining part of the superior temporal gyrus, i.e., of area 22).

Association area (Auditopsychic)

1. **Area 22. Situation**—Superior temporal gyrus. **Functions**—(*a*) A small part of it is included in the auditory centre. (*b*) Greater part acts as the *auditopsychic* area. The auditopsychic area is represented unilaterally. In the right-handed person it is on the left side and in the left-handed person it is on the right side.

2. **Areas 21 and 20. Situation**—Middle temporal and inferior temporal gyri respectively. **Function**—*Auditopsychic area.* Analysis, interpretation and integration of auditory impulses take place. The auditopsychic area is represented unilaterally. In the right-handed person it is on the left side and in the left-handed person it is on the right side. [The speech centre is just in front of it on the anterior aspect of central sulcus.]

Motor area (Adversive)

Temporal adversive field—Posterior part of area 22.

Lesion of the temporal lobe results (*a*) auditory disorders, (*b*) disturbances of smell, (*c*) aphasia—(if the lesion is near the posterior end of the Sylvian fissure), (*d*) Visual hallucinations, and (*e*) dreamy states.

Temporal lobe syndrome. After bilateral removal of temporal lobes along with the uncus (FIG. 5.232) and amygdala in monkeys following changes were observed.

(1) Inability to recognise objects (*visual agnosia*). (2) Tendency to examine all the objects by putting them into the mouth (*oral tendencies*).

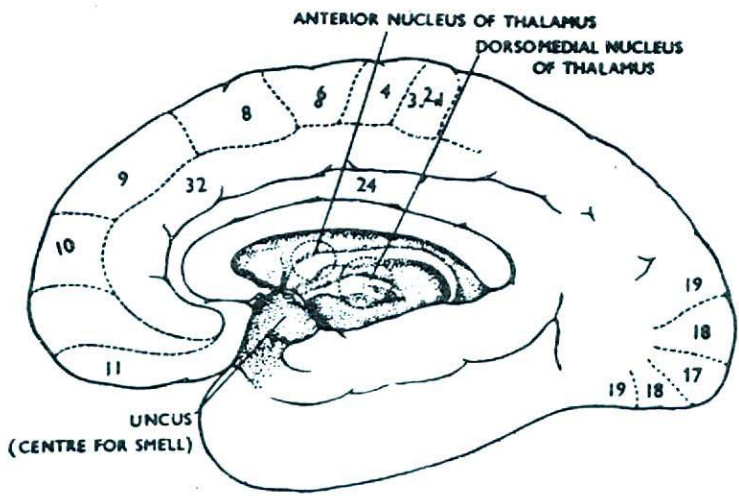


FIG. 5.232. Diagrammatic representation of the medial surface of the cerebral hemisphere showing uncus and other areas.

(3) Peculiar attention to different objects (*hypermetamorphosis*). (4) Changes in emotional behaviour. The animals showed no signs of fear and remained tame (*tameness*). (5) Striking increase in sexual behaviour and its diversity (*hypersexuality*). (6) Dietary habits are changed. The monkey accepts meat which is not accepted in general case.

IV. OCCIPITAL LOBE (mostly **sensory** and **association** areas, viz., Visuosensory and Visuopsychic areas. Only slightly motor—*adversive*).

Sensory area (Visuosensory)

Area 17. Situation—Posterior pole and calcarine fissure of occipital lobe—visuosensory area. Like the auditosensory area the visuosensory area is also grouped into **visuosensory area I** and **visuosensory area II** (FIG. 5.233). **Function**—*Cortical visual centre.*

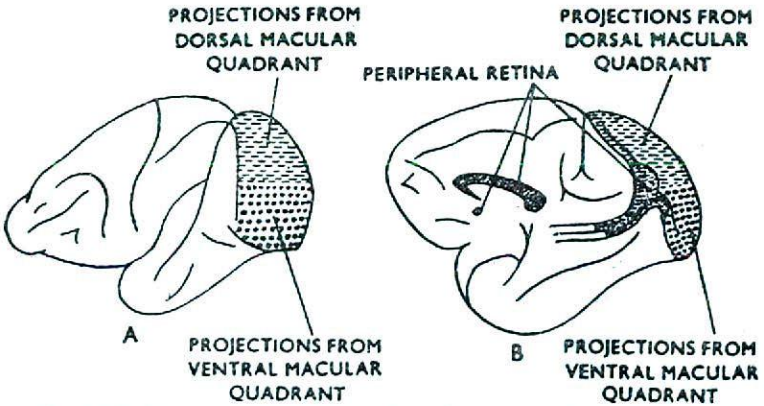


FIG. 5.233. Diagrammatic representation of occipital lobe showing visual projection areas and stippled parts representing the peripheral retina. A = Lateral surface of cerebral hemisphere and B = Medial surface of cerebral hemisphere.

Association area (Visuopsychic)

Area 18. Situation—On the convexity—just above area 17. **Function**—*visuopsychic area.* Here, the exact meaning of a visual image is interpreted and integrated, such as the meaning of written language. *Subjects with lesion in this area will fail to understand written language.*

Motor areas

Area 19 (Occipital eyefield—*adversive*). **Situation**—just above area 18. Stimulation of this area causes conjugate deviation of the eyes towards the opposite side (same as area 8). Association fibres are believed to proceed from this area to the frontal eyefield. Hence, the conjugate deviation. These fibres are included in the path of accommodation (*vide* under Accommodation).

Area 19s. Situation—In the occipital lobe anterior to visuopsychic area. **Function**—inhibits resting cortical potential.

V. LIMBIC LOBE AND LIMBIC SYSTEM

Limbic lobe is phylogenetically old *palaeocortex* and is called *allocortex*. Between the allocortex and the rest of the cerebral hemisphere there

is a transitional type of cortex which is known as *juxtallocortex* or *mesocortex* (Fig. 5.234). The *allocortex* is developed in association with the chemical

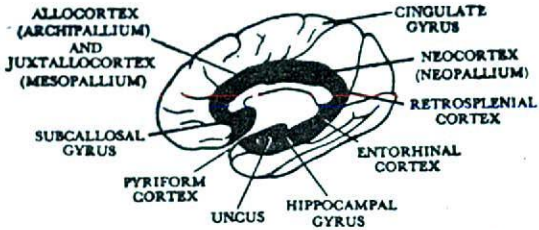


Fig. 5.234. Diagram showing the anatomical relationship of the limbic cortex with the rest of the cortex in human beings.

senses and thus known as **olfactory cortex** or **rhinencephalon** and phylogenetically, having six characteristic layers (Fig. 5.235) is described as **neocortex (isocortex).** "The neocortex sits astride the limbic system like a rider on a horse without reins." But the rhinencephalon or olfactory cortex is a more restricted term and it includes only those portions of the brain which receive projections from the olfactory bulb. Specifically, the **limbic lobe** includes the *subcallosal cingulate* and *parahippocampal gyri* as well as the underlying *hippocampal formation* (hippocampus, dentate gyrus, indusium griseum or supracallosal gyrus and the longitudinal striae).

The **limbic system** is a more generic term and includes all of the limbic lobe and the associated subcortical nuclei such as the *amygdaloid complex*, *septal nuclei*, *hypothalamus*, *epithalamus* (pineal body, habenular nucleus, stria medullaris, epithelial roof of the third ventricle), *anterior thalamic nuclei*, parts of the *basal ganglia* and *midbrain reticular formation* (Fig. 5.236).

The **olfactory centre** is situated in the uncinate part of the hippocampal gyrus.

In 1958 Penfield and Milner observed that there was loss of recent memory after bilateral removal of hippocampal gyrus and hippocampus (hippocampal formation) in a patient. In human being the hippocampus, fornix, cingulate gyrus, are well developed and so it has been suggested that beside olfaction they subserve more important functions in the body.

Afferent and efferent connections of limbic system. The interconnection of the limbic system is complex and not fully worked out. The main connections of the limbic

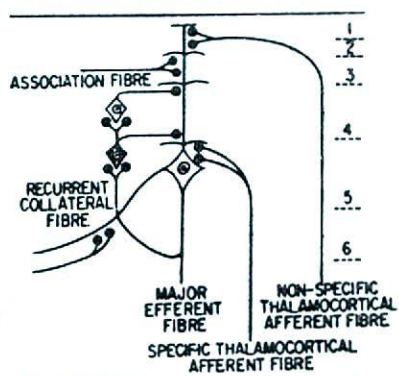


Fig. 5.235. Diagrammatic representation showing the connections of neocortical neurones. Descending axons of the giant cell give off collateral fibres in the pyramidal cell layer. These collaterals feedback through association fibres to the cellular dendrites. Recurrent collateral fibres connect to adjacent cells and a few recurrent collaterals end on inhibitory neurones. Specific thalamocortical afferent fibres end in the fourth layer and non-specific thalamocortical afferents end in the first layer (*after Ganong*).

system have been represented in Fig. 5.236. The fornix connects the hippocampus with Ammon's horn to different hypothalamic nuclei and the

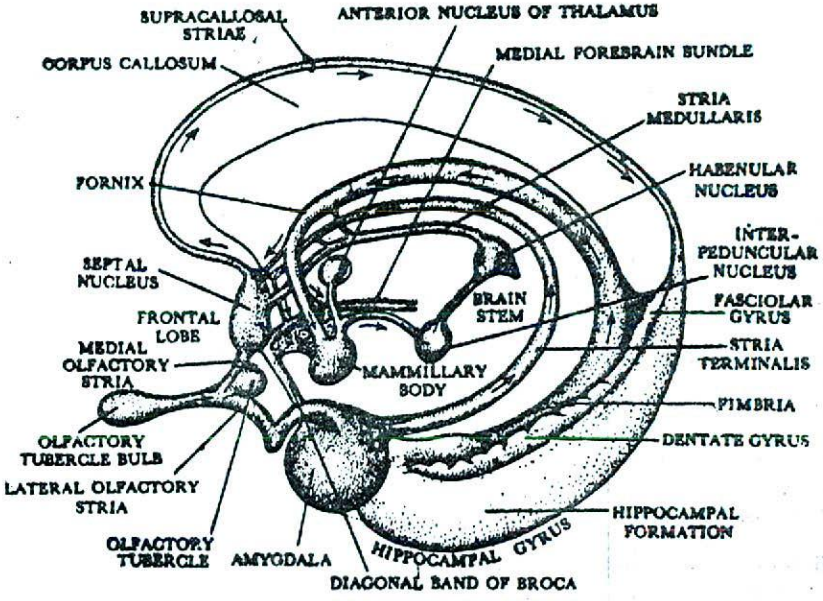


Fig. 5.236. Diagram showing the main connections of the limbic system.

mammillary bodies of the hypothalamus are connected to the anterior nucleus of the thalamus through the mammillothalamic tract. The anterior nucleus of the thalamus (*vide* page 5-170) sends fibres to the cingular (cingulate) cortex (areas 23, 24, 29, 32). The hippocampus and the septal region thus project to the hypothalamic nuclei mainly through the fornix. The caudate nucleus receives fibres from the cingular gyrus and the intralaminar nuclei of the thalamus. The lateral hypothalamus receives fibres from the following: (*i*) hippocampal and septal zones, (*ii*) olfactory tubercle, (*iii*) head of the caudate nucleus, (*iv*) prepyriform and periamygdaloid cortex (Fig. 5.237).

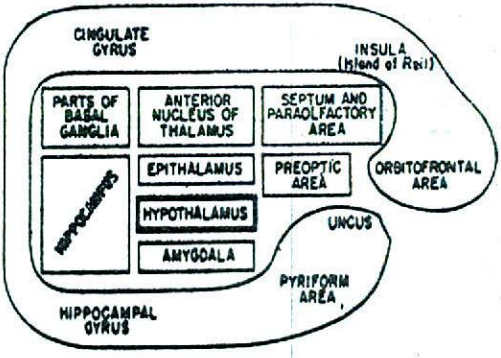


Fig. 5.237. Simplified diagram of the limbic system (*after Guyton*).

However, the different parts of this system are closely connected with one another and, on the other hand, with secondary sensory areas and

association areas of the isocortex, i.e., medial surfaces of the frontal, parietal, temporal and occipital lobes.

Functions of the limbic system

The limbic system is concerned with **emotional reaction, visceral, somatic, behavioural changes, motivation, biological rhythms, respiratory, circulatory** and **endocrine changes.**

Bilateral lesion of the amygdaloid complex in monkey and cat markedly produce disturbances in **emotional behaviour.** The animals become aggressive.

Decorticate rage produced after decortication is not due to removal of neocortex alone but due to removal of amygdaloid complex along with it. This amygdaloid nucleus has got some inhibitory effect over the neural structure responsible for this rage reaction. It has been observed that hypothalamic nuclei are the neural structures which are responsible for this rage reaction. Amygdaloid complex keeps the hypothalamic rage reaction in check through their projection fibres on the ventromedial nucleus of the hypothalamus, and after destruction of which causes calm cat to become furious or savage.

After a few days of lesion of the amygdaloid nucleus the animals become hypersexual and the animals mount over others irrespective of species and sex. It has been noted that hypersexuality is due to lesions of the pyriform cortex, because lesion of the amygdaloid nucleus without disturbing the pyriform cortex do not produce hypersexuality. Bilateral lesion of the amygdaloid complex in man reduces the emotional excitability and normalises its social behaviour.

Electrical stimulation of the amygdaloid complex produces emotional, visceral, somatic and other endocrine changes. These changes include alteration in respiratory rate, depth and rhythm. Cardiovascular responses are either increased or decreased. Gastro-intestinal motility is either increased or decreased. Salivation, piloerection, pupillary changes, alteration in body temperature are also encountered. Endocrine activities such as excess secretion of gonadotrophin and adrenocorticotrophic hormones from the anterior pituitary are observed.

Stimulation of amygdaloid nucleus may act as **reward** because a pleasurable sensation is felt by the animal during stimulation. For this pleasurable sensation, implanted electrodes in the amygdaloid nucleus or in the septum are often stimulated by the animals themselves for as long as 48 hours without sleep (Fig. 5.238).

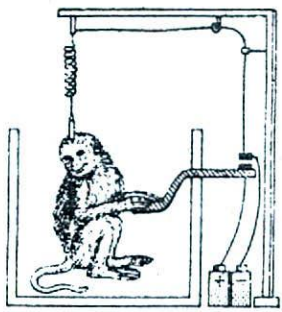


Fig. 5.238. Diagram showing the apparatus in self-stimulation technique for localising and reward centres in the brain of a monkey. When the monkey is pedalling each time, the electrical circuit is closed and the single current is passed to its brain *via* implanted electrode.

It is understood that the normal functions of the amygdaloid nuclei are to help in controlling the overall pattern of behaviour, required for such occasion.

Stimulation of the different regions of the hippocampus produces involuntary, tonic or clonic movements. Remarkable effect of

the stimulation in man is the immediate loss of contact with the man with whom he is talking. Weak stimulation may produce epileptic seizure in this region.

Bilateral removal of the anterior cingular gyrus causes increased tameness of the animals and previous rage and anger are disappeared. Bilateral ablation of the posterior portion of the fronto-orbital cortex often causes an animal intense restless.

Stimulation of the anterior cingular cortex and the **orbital-insular-temporal cortex** produces elevation or depression of the arterial blood pressure. The most striking effect is the inhibition of respiration. Other effects are inhibition of peristalsis, pupillary dilatation, salivation, bladder contraction, and inhibition of spontaneous movements.

The limbic systems are concerned with the regulation of biological rhythm (the circadian rhythm or diurnal rhythm). Lesion of the fornix modifies such rhythm in the adrenocortical functions.

As the hypothalamus is included within the limbic system the behavioural and emotional changes, autonomic changes, etc., are also due to the hypothalamic functioning (*vide* Hypothalamus).

Functions of the limbic system is complex and multiple; and thorough studies on this system are still required.

Though the limbic system is known as visceral brain yet there are certain areas within it which have got no visceral functions at all and somatic functions are intermingled inseparably with certain visceral functions.

Insular area

Situated in the whole of insula **(island of Reil)** (FIG. 5.239). **Function**—not yet fully known. However, on electrical stimulation the activities of the alimentary tract are involved. Functions of the long and short

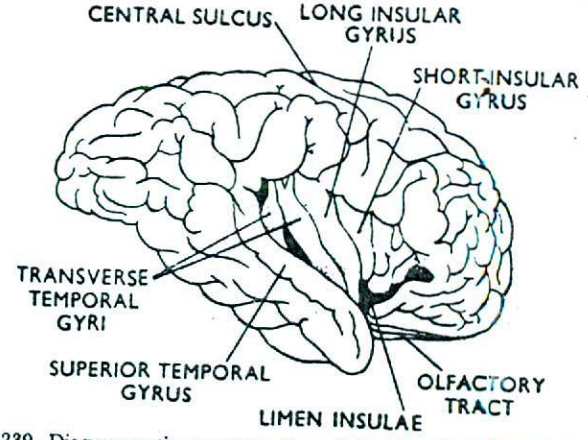


FIG. 5.239. Diagrammatic representation of the lateral surface of the right cerebral hemisphere showing insula after drawing apart the opercula of the lateral sulcus.

insular gyri are similar with those of the temporal gyrus and parahippocampal gyrus respectively. This area does not connect with the thalamus afferently.

Functions of the cerebrum

Functions of the cerebrum may be divided (FIG. 5.240) into the following groups:

I. Motor functions

Altogether there are three motor levels in the central nervous system. The **anterior horn cells** *constitute the first level, the* **pyramidals**—*the second, while the* **extrapyramidals** *make up the third level.* The **functional difference of the three** must be clearly understood. The anterior horn cells are the basic motor units, each one controlling a few muscle fibres or utmost one individual muscle. One pyramidal cell, on the other hand, controls many anterior horn cells and as such, the co-ordinated movements of a number of muscles, for instance, the extension or flexion of a limb. The extrapyramidal cortex also controls the anterior horn cells and regulates the skilled group movements of a large number of muscles, such as walking, writing, etc.

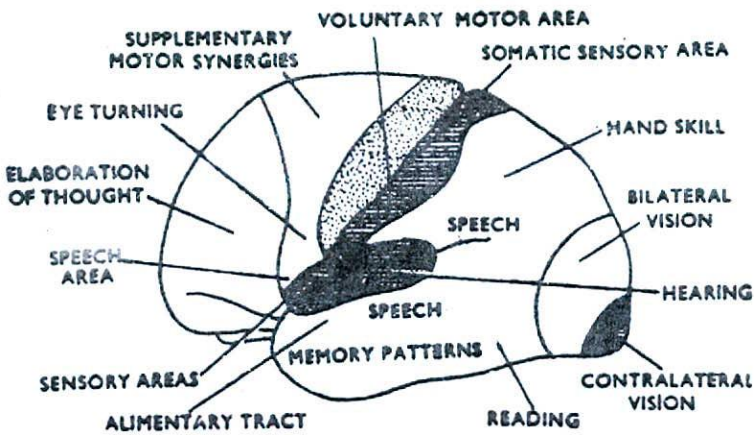


FIG. 5.240. Diagrammatic representation of functional areas of the human cerebral cortex.

1. **General motor function:** Volitional movement—controlled by area 4. [*Vide* page 5-231.]

2. **Special motor functions:**

(*a*) Regulation of tone, posture, equilibrium.
(*b*) Regulation of automatic and associated acts.
(*c*) Control of autonomic nervous system (corticothalamo-hypothalamic).
(*d*) Tonic inhibitory control over lower motor centres.

} Chiefly controlled by area 6 and to some extent by area 4. [*Vide* page 5-232.]

(*e*) **Speech. Broca's area**—In the right-handed people, situated in the left inferior frontal convolution (area 6b). In the left-handed subjects—opposite.

(*f*) Control of eye movements—(*i*) *Frontal eyefield*, area 8—Cortico-nuclear fibres arise here and end round the third, sixth and fourth nuclei

of the opposite side. (*ii*) *Parietal adversive field*—area 5b. (*iii*) *Occipital eyefield*—area 19. (*iv*) *Temporal adversive field*—posterior part of area 22. The adversive areas not only cause the eye movements but also those of head and body to the opposite side.

II. Seat of conditioned reflex

Cerebral cortex is responsible for the establishment of conditioned reflexes through the development of new connection with different subcortical centres. For establishment of conditioned response or reflex (CR) through specific conditioned stimuli (CS), specific cortical and subcortical centres are responsible for its development. As for example, for the production of conditioned salivation reflexes, the cortical taste centre as well as the visual and auditory areas along with its subcortical centres are responsible if the CS are the ringing of bell and giving of food.

III. Sensory functions

1. **General senses:** Perception of touch, pain, heat, cold and kinaesthetic sensations. *Centre*—Somaesthetic area (Parietal lobe). Includes areas 3, 1, 2 and 5, 7. The last two act as psychic association areas, while the first three are mainly receiving areas. In the somaesthetic area the complete meaning of a particular sensation is understood, such as (*a*) Appreciation of the size, shape, texture and weight of the objects—**stereognosis.** (*b*) Appreciation of the relative intensity of the different stimuli. (*c*) Tactile localisation, tactile discrimination of two points, recognition of position and passive movements of the limbs—**spatial recognition.**

2. **Special senses:**

(*a*) **Taste.** Inferior part of the postcentral gyrus. Here, general and taste sensations are perceived. Lesion of this area results in loss of general and taste sensations on the opposite half of the tongue.

(*b*) **Smell.** Uncus and hippocampal gyrus (allocortex). Here, olfactory sensations are perceived.

(*c*) **Vision**—

(*i*) **Visuosensory centre.** Occipital lobe (area 17). Here, all visual impulses are perceived.

(*ii*) **Visuopsychic area.** Area 18. Here, the exact meaning of a visual image is interpreted and integrated, such as the meaning of a written language.

(*d*) **Hearing**—

(*i*) **Auditosensory centre.** Heschl's gyrus (areas 41, 42) and the adjoining part of superior temporal gyrus (area 22). Here, the pitch, loudness, quality, etc., of the sound are appreciated. *The centre is* **bilateral.**

(*ii*) **Auditopsychic centre.** Temporal lobe (areas 22, 21, 20). Here, the analysis, interpretation and integration of auditory impulses take place and the complete associative meaning of a sound is recognised. It is **unilateral.** *Like the speech centre, it is located in the left temporal lobe in the right-handed subjects and in the right temporal lobe in the left-handed subjects.*

IV. Intellectual functions

Cerebrum is responsible for all intellectual functions, viz., memory, intelligence, planning, judgement, etc. The so-called silent or association areas (psychic areas) are responsible for this—chiefly the prefrontal lobes. The prefrontal lobes associate themselves with other areas of the brain,

viz., parietal, occipital and temporal lobes through the association fibres and act as planning organs and help in complex intellectual activities. [*Vide* pages 5.235—5.236.]

The development of prefrontal lobes bears a direct relation to the intelligence of the animal in the phylogenetic scale. But one must realise that these higher mental faculties cannot reside only in the prefrontal lobes. Because, intelligence depends on the ability to receive, respond and adapt. Obviously these are determined by the memory of all past impressions received through all the sensory organs. By associative faculties these sensory impressions are synthesised into various complex patterns and are stored as 'memory'. Whenever a new impression comes, its full significance is understood by analysing it in the background of this 'memory' and an appropriate motor response is accordingly organised. This whole process is called *intelligence*. Mental capacity will, therefore, depend not only on a particular lobe, but on the co-ordinated activity of the brain as a whole. The special value of prefrontal lobe lies in its high associative abilities.

ELECTRICAL ACTIVITY OF THE CEREBRAL CORTEX

The electrical activity of the brain and cerebral cortex is complicated and of different types from those of single nerve fibre or neurone. This is due to a large number of neurones, synapses and various properties of synapses, such as inhibition, summation, facilitation, etc., are integrated together to give rise rhythmic electrical potential changes which can be recorded through suitable instruments like **electroencephalograph** or **cathode-ray oscilloscope.** The electrical activity of the cerebral cortex is of mainly two types—*spontaneous* and *evoked*. The spontaneous electrical activity of the brain is the **electroencephalogram** which is described below.

Electroencephalography

Like other cells, nerve cells also show changes of electrical potential during activity. With an instrument called *electroencephalograph* the waves can be detected, amplified and recorded. Such a record is called *electroencephalogram*. Hans Berger who was a German scientist, first introduced the term electroencephalogram (EEG). Berger in 1929 recorded changes in the electrical potential by placing electrodes on the scalp of the human beings. These electrical potentials were later investigated by Adrian and Matthews. *Electrocorticogram* is the term sometimes used to denote the record obtained with electrodes on the pial surface of the cortex. Berger also detected the changes by placing minute electrodes on the surface or within the substance of the cerebral cortex in animals (**electrocorticogram**).

ELECTROENCEPHALOGRAM (EEG)

I. Spontaneous electrical activity

The *spontaneous electrical activity* from the brain as recorded by the electroencephalographic machine with the help of scalp electrodes through the lead is called **electroencephalogram** which has been most effectively studied in human beings.

Electroencephalogram. Electroencephalographic records may be *bipolar* or *unipolar* and consists of different types of rhythmic waves. Bipolar is the record of potential fluctuations between two cortical electrodes, whereas the unipolar electrode is the record of potential differences between a cortical electrode and an indifferent electrode placed on some part of the body.

Alpha, beta, theta and delta waves. In normal human subjects four types of waves are recorded, e.g., *alpha* (α), *beta* (β), *theta* (θ) and *delta* (δ) (FIG. 5.241).

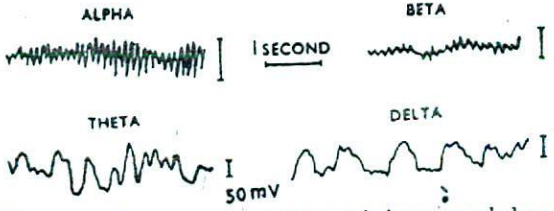


FIG. 5.241. Diagrammatic representation of normal electroencephalographic *alpha*, *beta*, *theta* and *delta* waves.

Alpha waves. *Alpha waves* (*rhythm*) are the most prominent synchronised rhythmic potential changes, found with eyes closed or in dark, when the brain is under quiet rest. Usually found in the occipital cortex, but also obtained in frontal and parietal regions. This rhythm is marked in occipitoparietal region. Any mental exertion, even with closed eyes, will disturb. The alpha waves disappear when eyes remain open. This alpha wave is disappeared with a replacement of fast, irregular and low voltage activity without any dominant frequency just after opening the eye. This phenomenon is known as **α-block.** This α-block is due to desynchronisation of regular (synchronised) α-rhythm by any kind of sensory stimulation. This desynchronisation response is also called arousal or



FIG. 5.242. Diagram shows the changes of alpha rhythm after opening and closing the eyes.

alerting response (FIG. 5.242). Visual stimuli, mental concentration, etc., abolish alpha waves. During deep sleep, the alpha waves disappear entirely and with a specific mental activity the alpha waves are replaced by asynchronous high frequency low-voltage waves. The dream is accompanied by alpha waves. The alpha waves cannot occur without the connection of the reticular activating system. It is postulated that the reverberation between thalamus and cerebral cortex and also the recruiting response of the thalamus are responsible for the cause of the periodicity of the alpha waves. **Rate**—8–12 cycles per second. **Amplitude**—highest —average 50 microvolts (FIG. 5.243).

Beta waves. Usually found in the parietal and frontal regions of the scalp. **Rate**—about 18 cycles per second and maximum 60 cycles per second. **Types:** *Beta I waves* have a frequency about twice that of *alpha* waves and disappear during reaction of mental activity, but such waves are replaced by asynchronous low-voltage waves. *Beta II waves* appear during tension or during intense activation of the central nervous system. **Amplitude**—5–10 microvolts (less than *alpha* waves)—low voltage fast waves (FIG. 5.243).

Theta waves. Usually found over the parietal and temporal regions. In children between the ages two and five years theta waves are prominent. **Rate**—4–8 cycles per second. **Amplitude**—10 microvolts.

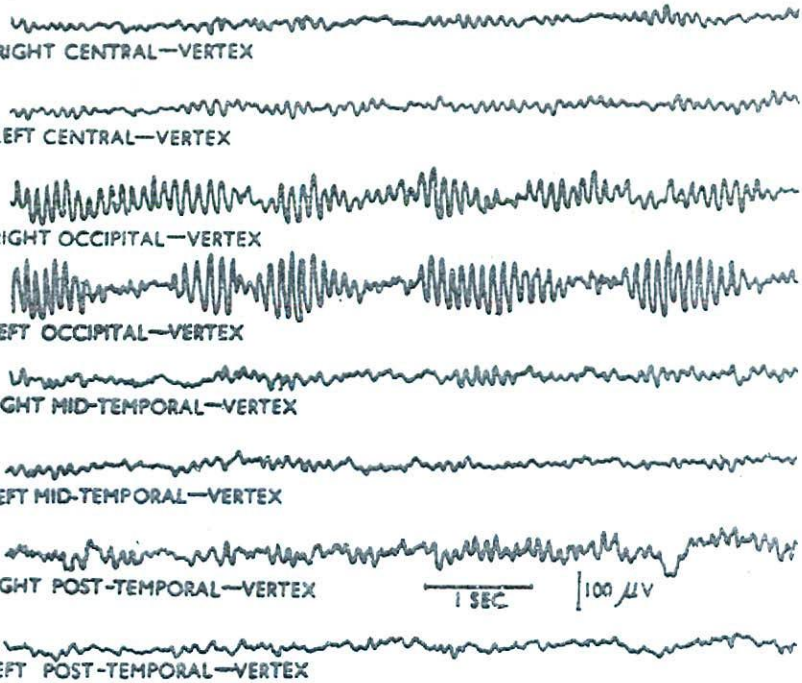


FIG. 5.243. Normal electroencephalogram from different cortical areas in man showing *alpha* and *beta* waves during awake with eyes shut.
By courtesy of Dr. T. K. Ghosh, M.D. (Cal.), Head of the Department of Neurology, University College of Medicine, Calcutta.

Delta waves. It is postulated that the *delta* waves occur due to separation of the cerebral cortex from the reticular activating system. Rarely found in normal adults during waking periods, but usually found during deep sleep and in serious organic brain disease. In severe hypoxia and also in hypoglycaemia δ-waves appear frequently. In infancy it appears both during deep sleep and waking. **Rate**—Minimum, 0·5–3·5 cycles per second. **Amplitude**—variable 20–200 microvolts—high voltage slow waves.

Conditions that alter the electroencephalogram (EEG) pattern

Different factors may alter the EEG pattern. These are discussed below:

1. **Age.** Dominant EEG rhythm may vary with age. δ- and θ-waves are the characteristic features of infancy and childhood. In infants there is fast β-like activity but with the advent of adolescence gradual α-pattern appears.

2. **Blood-glucose level.** Blood sugar level has got profound influence on the EEG pattern. Hypoglycaemia decreases the frequency of

α-rhythm and even causes appearance of δ-rhythm but the α-rhythm is not totally abolished. Hyperglycaemia has got little effect on cortical potential.

3. **Hypoxia.** Mild hypoxia initially slowers the rhythm but if the state is severe then causes appearance of δ-waves.

4. **Effect of CO_2.** High arterial CO_2 tension may cause slowing of the frequency of α-rhythm. Washing-out of CO_2 is used clinically to bring out latent EEG abnormality.

5. **Temperature.** Lowering of body temperature may sometimes decrease the frequency of α-rhythm.

6. **Sensory stimulation.** Any type of sensory stimulation alters the EEG pattern. Pattern of α-rhythm is altered with attention and mental concentration. But in full mental rest, there is appearance of α-wave but with attempt of solving a mathematical problem it is abolished by fast and irregular low voltage activity.

7. **Sleep and EEG.** As soon as a subject gets relaxed, he feels drowsy and gradually falls asleep. α-pattern of EEG is replaced by slower and larger waves. In deep sleep there are often irregular δ-waves having frequency less than 4 per second (Fig. 5.244).

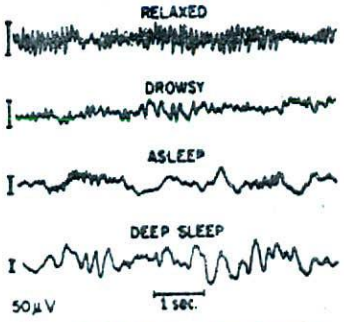


Fig. 5.244. EEG patterns under certain conditions (*after Ganong*).

The EEG pattern of deep sleep is sometimes replaced by low voltage and high frequency irregular waves along with eye movements. This type of sleep is known as **paradoxical sleep** and for the associated movements of eyes it is also called **rapid eye movement sleep** (REM sleep) (Fig. 5.245).

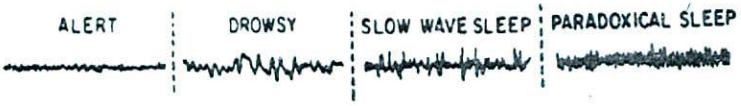


Fig. 5.245. Sequential changes of EEG in a subject during alert, drowsy, slow-wave sleep and paradoxical sleep.

Sleep having high voltage (spindle) slow wave EEG pattern but unassociated with eye movements is also called **slow-wave sleep** or **non-rapid eye movement sleep** (NREM sleep). REM sleep occurs at about every 90 minutes of sleep period.

8. **Narcotics.** With narcotics the α-waves are replaced by δ-waves. The rhythm of α-waves is decreased by low glucose level, lowered body temperature, anaesthesia or analgesia, sleep, etc.

Electroencephalogram in various diseases

Changes in the electroencephalogram have been noted in the following diseases.

1. **Increased intracranial pressure.** Berger demonstrated slow δ-waves with an amplitude up to 100 microvolts and a frequency of

3 cycles per second during the rise of intracranial pressure due to cerebral tumours, concussion, meningitis, etc.

2. **Cerebral tumours.** Berger also demonstrated similar slow δ-waves arising from the affected region of the brain. The tumours cause progressive destruction of cortical tissue and as a result abnormally large slow δ-waves will arise from the damaged cerebral cortex (FIG. 5.246).

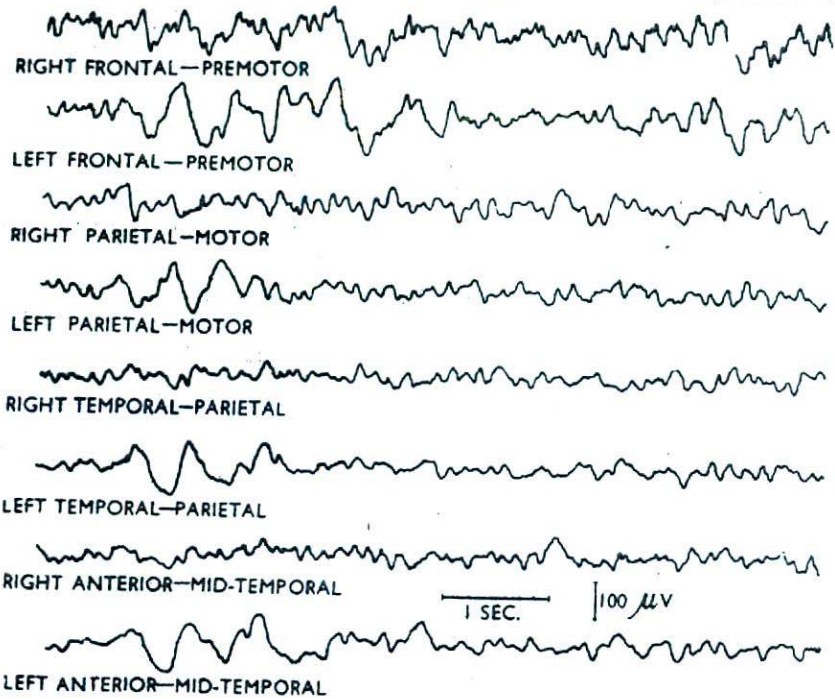


FIG. 5.246. Electroencephalogram of brain tumour in left parietotemporal regions showing *delta* waves.

By courtesy of Dr. T. K. Ghosh, M.D. (Cal.), Head of the Department of Neurology, University College of Medicine, Calcutta.

3. **Epilepsy.** It is a disorder, characterised by an abnormal and severe discharge of nervous energy from either a part of the central nervous system, usually the cerebral cortex or all of it. There are mainly two types of epilepsy: (*a*) generalised epilepsy, and (*b*) partial epilepsy.

The **generalised epilepsy** is of three types—*grand mal*, *petit mal* and *psychomotor* (FIG. 5.247). In the **grand mal type** there is generalised convulsions along with abrupt loss of consciousness. This seizure lasts for three seconds to as long as four minutes and is characterised by post-seizure depression of the entire nervous system. The *grand mal attack* is presumably due to increased activities of the mesencephalic (midbrain) part of the reticular activating system.

The **petit mal epilepsy** occurs in two different forms: (*i*) the *myoclonic form*, and (*ii*) the *absence form*. In the **myoclonic petit mal epilepsy,** the

subject exhibits a single violent muscular jerk (head or arms) and it lasts only for a few seconds. In the **absence petit mal epilepsy,** it is characterised by 4 to 22 seconds of unconsciousness along with several twitch-like contractions of the muscle usually in the head region. The electroencephalographic record shows spike and dome pattern (Fig. 5.248). In **petit mal attack** large but slow and irregular waves are recorded just before the

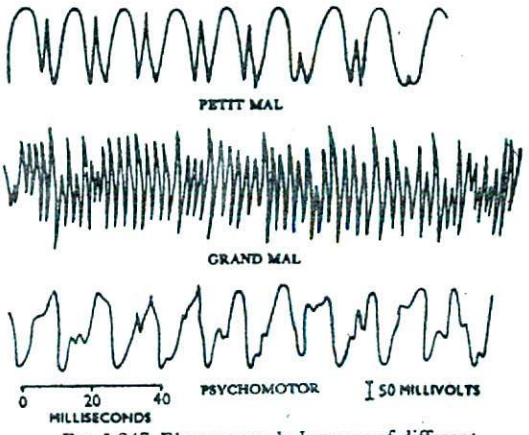


Fig. 5.247. Electroencephalograms of different types of epilepsy.

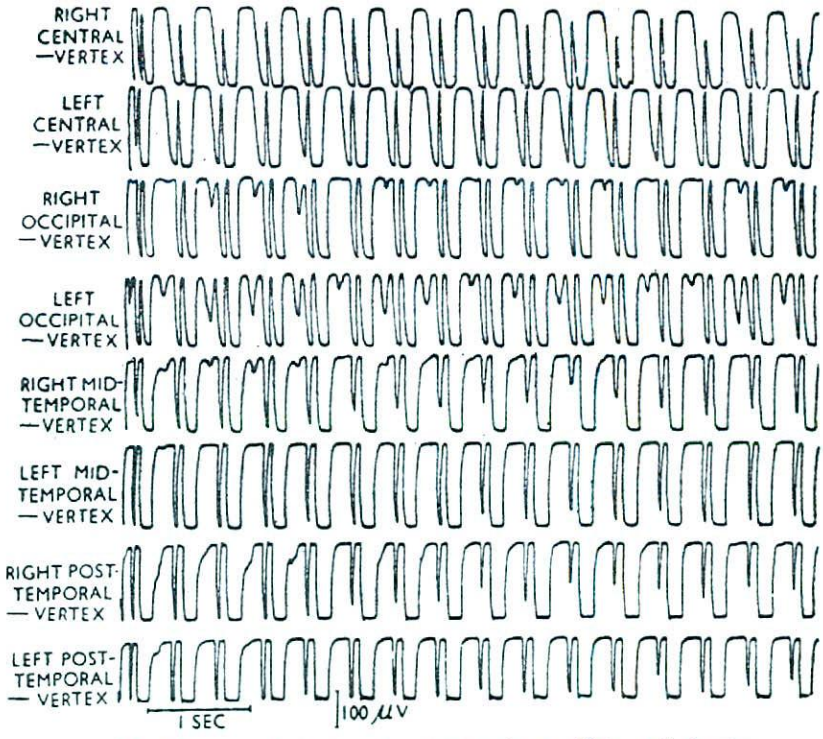


Fig. 5.248. Electroencephalogram of epileptic seizures (petit mal) showing spike and dome pattern.

By courtesy of Dr. T. K. Ghosh, M.D. (Cal.), Head of the Department of Neurology, University College of Medicine, Calcutta.

attack. A sharp spike deflection follows the large wave. An increase In the number of these spike waves often precedes a **grand mal attack** and indicates the onset of convulsion.

According to Gibbs, Gibbs and Lennox, the *seizure* waves in grand mal attack are sharp spikes occurring at 25 to 30 cycles per second and in petit mal attack there are sharp spikes alternating with slow round waves at 3 cycles per second.

Psychomotor is characterised by the automatic movements, i.e., chewing, smacking of lips, etc., along with a dreamy feeling of unreality. It is said that this type of psychomotor seizure is commonly due to **disturbances in the temporal lobe.** The **hypothalamic tumour** may cause the **outbursts of autonomic phenomena.** During a **psychomotor attack** there is a low frequency of rectangular wave with the frequency of 2–4 cycles per second and with the fast frequency of 14 cycles per second. This type of epileptic attack may cause an attack of abnormal rage, a short period of amnesia, a moment of incoherent speech, sudden anxiety or fear or discomfort.

Partial epilepsy or **localised epilepsy** is often of different forms and generally referred to as Jacksonian epilepsy. **Motor Jacksonian epilepsy** involves any localised area of the cerebral cortex or deeper structure of the cerebrum or the brain stem. The **seizure** is characterised by turning of the head and eyes towards the side opposite the lesion in the brain (anterior part of the precentral motor cortex and also of the medial surface of temporal lobe). The **partial epileptic attack** may be confined to a single area of brain, but in several cases it excites brain stem reticular activating system so greatly that may initiate grand mal epileptic attack. Cerebral tumours, abscesses, traumatic scars, vascular abnormalities, etc., are the commonest cause of this attack.

Idiopathic or **cryptogenic epilepsy** is that type of epilepsy whose cause is unknown and cannot be explained with demonstrable lesion in the brain.

Conclusion. Electroencephalography is now widely accepted as a reliable method of studying the electrical changes occurring in the cerebral cortex during normal and abnormal conditions. It is helpful in localising the exact site of cerebral tumours, abscesses, etc. It is of special importance in investigating the presence of epilepsy and the types of fits that occur in the epileptic subjects. Besides, it is also helpful in the diagnosis and investigation of impaired cerebral functions in various diseases of cerebral cortex, head injury, etc.

Physiological basis of EEG

Source of EEG. Originally it was of opinion that EEG waves are the summated action potential of cortical cells discharging in a volume conductor. But present concept is changed and it is due to current flow in the fluctuating dipoles formed on the dendrites of the cortical cells and cell bodies. Cortical dendrites are the forest of densely units placed in the superficial layers of the cerebral cortex (FIG. 5.249). Dendrites are the sites of non-propagated hypopolarising and hyperpolarising local potential changes in the excitatory and inhibitory axo-dendritic synapses. Dendrites

are not the processes for conduction and do not propagate action potentials. Action potentials are propagated through the axonic terminals. When the excitatory axo-dendritic synapses are activated, current flow into and out in between the cell body and axo-dendritic endings, causing a wave-like potential fluctuation in the volume conductor. Thus EEG is the potential fluctuation in volume conductor, but not the action potential and is conducted through the axon only. Thus the dipole formed in between the dendrites and the cell bodies fluctuates constantly due to the excitatory and inhibitory axo-dendritic synapses.

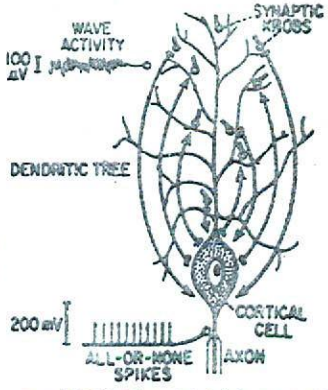


FIG. 5.249. The dendritic tree of cortical superficial neurone showing the development of wave pattern by current flow to and from active synaptic knobs on the dendrites
(after Bickford's Computational aspects of brain function and from Ganong).

Mechanism of desynchronisation and synchronisation. Definite pattern of α-rhythm is due to synchronised activity of the many dendritic units. When the synchronised activities of the dendritic units are disturbed by incoming different sensory impulses, the synchronised pattern of α-rhythm no longer persists and is replaced by desynchronised pattern of irregular low voltage activity.

For the genesis of synchronised wave pattern, two factors are responsible, such as (*i*) synchronising effects of two parallel nerve fibres, and (*ii*) the influences of impulses from the thalamus and the brain stem. The characteristic feature of α-wave indicates that the activities of many dendritic units are synchronised. Large bilateral lesions in the non-specific projection nuclei of the thalamus abolish the EEG synchrony.

Desynchronisation of EEG pattern with irregular low voltage activity can be produced by stimulating the specific sensory input up to the level of the midbrain. High frequency stimulation of the reticular formation in the midbrain tegmentum and of the non-specific projection nuclei of the thalamus desynchronises the EEG pattern.

II. Evoked cortical potentials

Evoked activity in the cerebral cortex is elicited by stimulating directly the cortical surface (*direct cortical response*—DCR) or by stimulating the peripheral sense organ like retina—by photostimulation, ear—by auditory click or the peripheral sensory nerve endings or fibres. A characteristic response is seen in each case which is greatly influenced by the effect of narcotics, drugs, physiological conditions like sleep, etc.

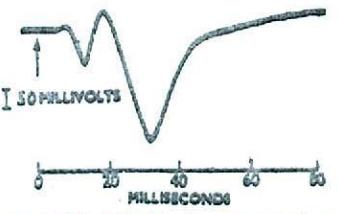


FIG. 5.250. Graphical representation showing response evoked in the contralateral sensory cortex by stimulation of the sciatic nerve.

The waves consist of surface positive, followed by small negative and

then by a larger more prolonged positive deflection (FIG. 5.250). The first positive-negative waves sequence is the *primary evoked response*, the second one is the *diffuse secondary response*.

Evoked and spontaneous electrical activities can be recorded directly from the cerebral cortex through either extracellular or intracellular recording with the help of microelectrodes (FIG. 5.251).

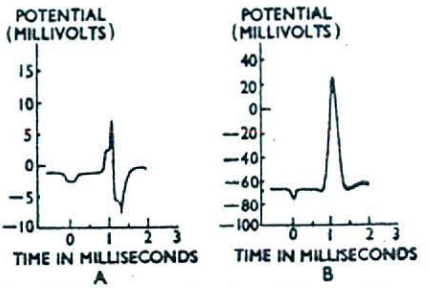


FIG. 5.251. Diagram showing discharge of Betz cells of the motor cortex stimulated by electrode at the cortical surface. A = recording *extracellularly* and B = recording *intracellularly*.

III. Other types of electrical activity in the cerebral cortex

Direct cortical (D.C.) potentials. During recording of the spontaneous electrical activity, the cerebral cortex shows certain changes in D.C. potentials which can be recorded through non-polarisable electrodes, sometimes recorded from the scalp also. The **steady potential (S.P.)** level of the cerebral cortex is originated from the polarisation state of the cortex and apical dendrites. A marked change is seen in the steady potential following asphyxiation. There is often a marked increase in electrical impedance (resistivity) of the cortex following asphyxia:

Spreading depression (S.D.). During recording of the spontaneous electrical activity, the cortical region very often shows temporary or transient inhibition of these rhythmic waves and this is believed to be due to the *spreading depression*.

A **depression phase** slowly spreads from the occipital region to another part of the frontal cortex at 2·5 mm per minute and successively invades one area after another followed by immediate recovery. This depression is the function of the apical dendrites and recovery requires the expenditure of metabolic activity. Release of potassium or glutamic acid is involved in the genesis of spreading depression.

SPEECH

Definition. *Speech is the production of articulate sounds, always bearing a definite meaning.* It is one of the highest faculties of brain brought about by the co-ordinated activity of different motor, sensory and psychic centres. *Speech*, *reading* and *writing* (written speech) are closely allied. When a sound is verbally reproduced—that is what we call **speech.** If it be expressed by visual symbols, that is known as **writing.** If visual symbols (written) are expressed verbally, that becomes **reading.**

Centre. One curious finding is that in the right-handed people the sensory, psychic and motor areas concerned with speech and are chiefly located in the left cerebral hemisphere. While in the left-handed people it is just the reverse. **Speech centre** lies in the left inferior frontal convolution area (6b). The **writing centre** is believed to be in the left middle frontal convolution area (6aα).

Development of speech

Like all complex motor processes, speech depends on the co-ordinated activities of a number of sensory, psychic and motor areas. When the baby learns speaking, it at first hears the sound of a spoken word (Auditosensory area), then it tries to understand the full meaning of the sound with the help of other sensory and associative impressions (Auditopsychic area). For instance, the word 'Papa' becomes linked up with a particular man. The baby then tries to organise the necessary motor impulses in a particular area called the **speech centre** (Broca's area). Thus organised, the stream of impulses are passed on to the adjoining pyramidal area, which control the movements of lips, tongue, larynx, pharynx, respiration, etc., i.e., those concerned with articulation. The impulses then travel down the pyramidal tracts to the motor centres of the corresponding nerves. In this way, the child produces the first sound. The first attempt naturally becomes defective. The defective sound is compared with the memory of the correct sound (Auditopsychic area). The child recognises the fault and tries again. Thus, after a long period of 'trial and error' (*lisping*) the sound becomes accurate. *In this way, speech develops. For speech, therefore, hearing is essential. A child who is born deaf is also born dumb* (unless special methods are adopted).

Writing is a very similar process. At first the visual impressions of the letters are received (Visuosensory area) and then their full meaning understood (Visuopsychic area). Then it is linked up with the centre for the complex movements of fingers and hands (Writing centre—area 6aα) and thus the hand 'writes'. Hence, vision is important for writing. [In blind schools, raised letters are used and thus alphabets are taught through tactile and kinaesthetic sensations.]

Reading is also a similar but a little more complicated process. The visual impressions of the letters and the auditory impressions of their sounds become mutually linked up in the corresponding psychic areas and are then associated with the speech centre. The following scheme summarises the three processes:

For speech:

Ear → auditosensory ('A') → auditopsychic → Speech centre ('B') → excitomotor centre → **speech**

For writing:

Eyes → visuosensory ('C') → visuopsychic → Writing centre ('D') → excitomotor centre → **writing**

For reading:

Eyes → visuosensory → visuopsychic → Speech centre → excitomotor centre → **reading**

auditopsychic

Aphasia. Various types of speech defects occur due to lesions of the sensory, psychic or motor areas responsible for speech, particularly **Broca's area** and neighbouring areas. The term *aphasia* is applied to those defects of speech which result from the disorders of higher nervous mechanism underlying the understanding of various sensory impulses (auditory, visual, kinaesthetic, etc.), the use of symbols (words, letters, figures, etc.) and the organisation of adequate motor impulses. *In other*

words, the defect lies in the psychical field. Those, resulting from paralysis of the muscles of articulation, are not true aphasias.*

Classification of aphasias

1. **Word-blindness.** (2 in FIG. 5.252). (Alexia, Visual aphasia, Nominal aphasia)—Inability to understand written or printed words. Cannot read or name the symbols, printed or written letters. But can speak or write spoken words. Lesions are centred on lower part of the posterior parietal lobule, angular gyrus, adjoining to occipital visual area, i.e., scheme on page 5-255 at the level of 'C'.

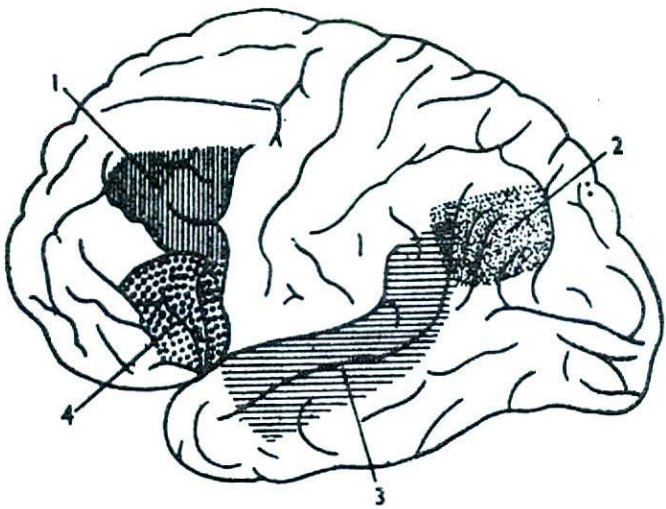


FIG. 5.252. Diagrammatic representation showing localisation of language functions. Lesion at 1 resulting difficulty in expressing ideas in writing (*agraphia*); Lesion at 2 causing difficulty in understanding written words (*word-blindness*); Lesion at 3 resulting difficulty in understanding spoken words (*word-deafness*); Lesion at 4 causing difficulty in expression (*pure motor aphasia*) (*after Ruch and Patton*).

2. **Word-deafness.** (3 in FIG. 5.252). (Auditory aphasia, Syntactical aphasia)—Inability to understand spoken words, but able to read and write although the reading is incoherent. The lesions are involved at the levels of superior and middle temporal convolutions adjacent to cortical area for hearing, i.e., scheme on page 1363 at the level of 'A'. Since the subject does not understand the meaning of his own words, he cannot rectify the faults of his speech. The subject is voluble and there is **jargon** speech.

Alexia (visual aphasia) and auditory aphasia are collectively known as **agnosia (semantic aphasia)**. These are commonly associated with mental defects.

3. **Pure motor aphasia.** (Apraxia, Verbal aphasia)—Inability to

* **Dysarthria** (Anarthria). Defects of articulation produce speech disturbances called Anarthria or Dysarthria (Stammering). It is caused by lesions of the excitomotor areas, pyramidal fibres, cranial nerves, extrapyramidal system or cerebellum.

speak articulately (4 in FIG. 5.255). Motor mechanism intact. No intellectual defect. Lesions lie at the region of anterior to the lateral end of the precentral gyrus, i.e., at the level of 'B' (scheme in page 5-255).

4. **Agraphia.** Inability to express the thoughts in writing although the muscles of hand are intact. Can read and speak. Injury lies at the finger region of premotor cortex (1 in FIG. 5.252), i.e., at the level of 'D' (scheme in page 5-255).

5. **Cortical aphasia.** For *Alexia, auditory aphasia, apraxia* and *agraphia*—Lesions are subcortical affecting the association fibres only. Hence, not much intellectual defect. But lesions of cortical gray matter disturb speech function as a whole and always cause intellectual defect. Lesions affecting the posterior parts disturb the *receptive* and *psychical* processes, while those situated anteriorly disturb the *motor* phenomena.

Head's classification of aphasias

Head has classified aphasias into four types: (*a*) Nominal aphasia. (*b*) Verbal aphasia. (*c*) Syntactical aphasia. (*d*) Semantic aphasia.

(*a*) **Nominal aphasia.** Difficulty in naming an object or inability to find suitable words to express the meaning of an object.

(*b*) **Verbal aphasia.** Inability to utter individual words of all types and to express thoughts in words although motor mechanism remains intact. It resembles pure motor aphasia.

(*c*) **Syntactical aphasia.** Inability to understand spoken words, but able to read and write although the reading is incoherent. The subject is voluble and there is **jargon** speech. The speech is in short phrases and defective.

(*d*) **Semantic aphasia.** Failure to understand one's own utterances and inability to grasp the meaning which it conveys.

NEUROPHYSIOLOGY OF LEARNING AND MEMORY

LEARNING

Learning is the most characteristic attributes of man and also of higher animals and by the process of learning the individual can change his behaviour by experience. Learning and memory are mediated by the nervous system. It is sometimes assumed to be the function of the cerebral cortex but it occurs in animals which have got no cortex. Learning is possible even in lower animals like worms and even in unicellular animals. Learning occurs in subcortical and spinal levels.

Different processes have been adopted for the study of the neurophysiological basis of learning, these are: (*i*) classical conditioning of Pavlov (Pavlovian conditioning), (*ii*) instrumental conditioning or learning, and (*iii*) discrimination learning.

1. Classical conditioning of Pavlov

The term *conditioning* is often used to represent all learning. We deal with conditioning in a much more limited sense. It means for us the acquisition of conditioned responses. Thus the term is used to represent a relatively simple aspect of the learning process. The response to be conditioned is already in the organism's repertoire. Therefore a conditioned reflex is a reflex response to a stimulus, which did not elicit the response previously, but acquired after repeated application with another specific type of stimulus that normally evoked such response.

As mentioned before (*vide* page 5–74) reflexes are of two classes: (1) *inborn or unconditioned reflex* (UR), (2) *acquired or conditioned reflex* (CR). The **characteristics** of conditioned reflexes are: (*a*) It is acquired in life, (*b*) Depends on previous experience, (*c*) Can be established or abolished, (*d*) Not transmitted by heredity, (*e*) Conditioned reflexes are established primarily upon some pre-existing unconditioned reflexes, (*f*) Cortical and subcortical centres are responsible for it. *Example:* Food stimulates salivary secretion. This is an unconditioned reflex. Now, if a second neutral stimulus, viz., ringing of a bell or flash of light, be applied just before or during the giving of food for some days, the bell sound or flash of light itself will be able to elicit the salivary reflex, even if no food be given at all (FIG. 5.253). Such a neutral stimulus is called *conditioned stimulus*. Pavlov

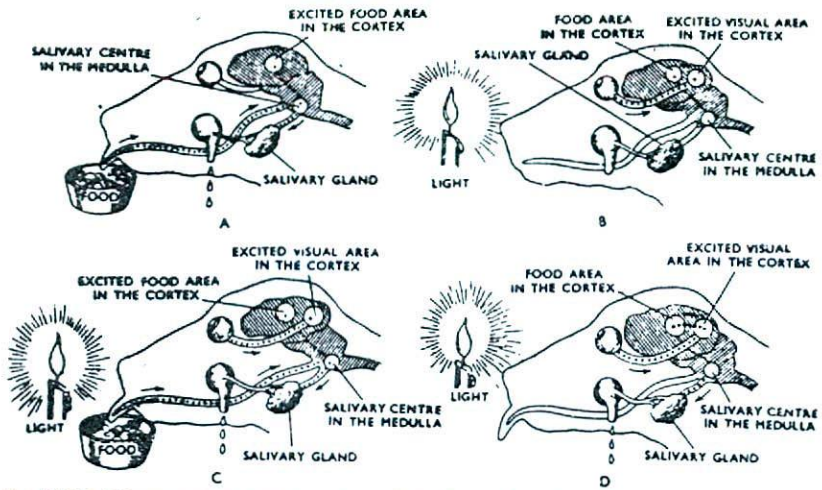


FIG. 5.253. Diagrammatic representation of the formation of conditioned salivary reflex. **A** showing unconditioning salivary reflex (*food*). **B** showing application of conditioning stimulus (*light*) before establishment of conditioning reflex where the visual area of the cortex excited but there is no conditioned response (CR). **C** representing application of a conditioning stimulus (*light*) with an unconditioning stimulus (*food*) visual area and food area in the cortex excited simultaneously. **D** showing establishment of CR by giving conditioned stimulus (CS) (*light*) only and the arrow indicates resultant momentary connection between visual area and food area in the cortex.

(1906) had carried this experiment in the dog, the dog associates the bell sound with the giving of food and starts salivation in anticipation. A good lot of mental analysis and association is required for the establishment of this reflex. This reflex has been termed by Pavlov as conditioned reflex (FIG. 5.254). The conditioning process may be represented schematically in such a way as to show the S–R relationships. Thus, before the salivary response is conditioned to a bell, the situation is as follows:

Unconditioned stimulus (*food*) ⟶ Unconditioned response (*salivation*)

Stimulus to be conditioned (*bell*) ⟶ Response (*pricking up ears, etc., but not salivation*)

After the stimulus to be conditioned has been paired with the unconditioned stimulus a number of times, and salivation in response to it (now the conditioned stimulus) has developed, the situation is as follows:

Unconditioned stimulus (*food*) → Conditioned response (*salivation*)

Conditioned stimulus (*bell*) ↑

The previously neutral or ineffective stimulus, as well as the unconditioned stimulus, now elicits salivation, i.e., salivation elicited by the bell alone is a conditioned response.

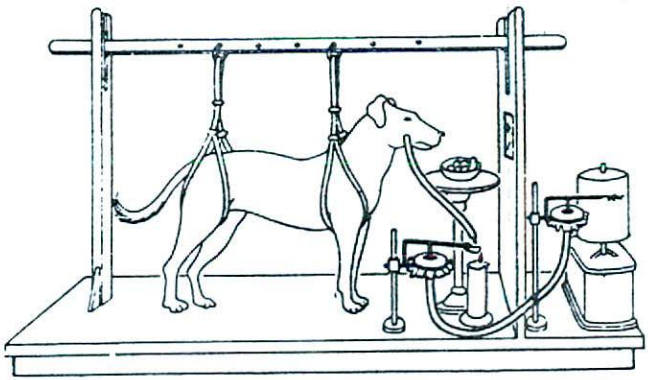


FIG. 5.254. Experimental procedure for demonstration of conditioned reflex or response (CR) in a dog (Pavlov's). Here the conditioned response (salivary secretion) has been recorded graphically by cannulating the salivary duct.

Pavlov confined his attention to dogs and, in those, to the salivary secretion. But Bekhterev extended the conditioned-response technique to human subjects. In his work with dogs and human beings, Bekhterev used an electric shock as unconditioned stimulus and reflex withdrawal of the shocked limb as unconditioned response. Various kinds of conditioned stimuli were used, including the beating of a metronome. The subject conditioned with this method gets the shock whether or not it responds to the conditioned stimulus. Bekhterev (1932) termed the response to the new stimulus an **associative reflex,** but later workers with this and related methods have adopted Pavlov's terminology.

The cerebral cortex is responsible for establishment as well as retention of learned habits. Because after establishment of conditioned habits, if the cerebrum is removed then the habit is no longer present. But in absence of cerebral cortex, certain conditioned reflexes can be established in presence of subcortical centres only. The subcortical centres gain the power of retaining the learned habits in absence of cortical centres, but in presence of cortical centres the subcortical centres have got little power of retention of learned habits. *Most of our habits are nothing but conditioned reflexes. A habit may, therefore, be described as an automatic response to a fixed set of conditions, acquired and established by infinite repetitions.*

Development of conditioned reflexes

(1) Conditioned reflex always develops on the basis of an uncondi-

oned reflex. (2) Speed of development is fairly quick, taking only a few ays. (3) The unconditioned stimulus must accompany or just precede the nditioned stimulus. (4) Any stimulus (general or special senses) may be ansformed into a conditioned stimulus. (5) The animal or the subject ust be conscious and must co-operate.

LASSIFICATIONS: (1) Positive or **excitatory**. (2) Negative or **inhibitory.**

Conditioned excitatory reflexes: EXPERIMENTAL FACTS

Summation. When same response is obtained by two conditioned sti-uli, the response will be bigger if two stimuli are simultaneously applied.

Irradiation. When a conditioned reflex is established by stimulating particular area of skin, the response will be lesser if a neighbouring area e stimulated. Greater the distance from the actual spot, lesser is the effect.

Specificity. The stimulus is more or less specific. If a conditioned reflex e established with a particular sound, a note with a different pitch will be ieffective, provided the animal has the power to recognise the difference.

Discrimination. This is another way of testing the law of specificity. f one sound be associated with the 'giving of food' and another with 'no ood', then by using a set of gongs whose vibrations lie somewhere between ne two sounds, the range of discrimination by the animal can be tested.

Decay. If a conditioned reflex be not elicited for several months it ndergoes decay (unresponsive) due to disuse.

Reinforcement. A decayed reflex may be fully revived by applying ne same conditioned stimulus several times. It is easily formed if the nconditioned stimulus is associated with a pleasant or an unpleasant ffect. Stimulation that follows with *reward system* is called **positive rein-orcement** and when it is associated with *avoidance system* or a painful hock—is termed **negative reinforcement.**

Linking. A second stimulus may acquire a conditioned value if it be nked up with the first conditioned stimulus. Suppose salivary reflex is stablished by using a gong sound as the primary conditioned stimulus. If ow, a second neutral stimulus, such as a flash of light, be applied just efore 10 seconds of the gong sound and if this procedure be repeated for number of days, then the second stimulus only will elicit the conditioned esponse Similarly, an endless series of stimuli can be linked up establish-ng secondary, tertiary, etc., reflexes. [If the second stimulus be simulta-eous it will have inhibitory effect.]

Trace phenomenon. Trace reflexes can be established by applying he unconditioned stimulus (food) *after an appreciable interval* following the onditioned stimulus (sound). When established, the reflex response ollows the conditioned stimulus after the same interval. According to the ngth of the interval the trace reflexes may be *short* or *long*.

Extinction. If the conditioned stimulus be repeated several times ithout unconditioned stimulus, reflex becomes extinct. Repeated disap-ointment creates a state of cortical inhibition so that no response occurs.

Induction. A positive conditioned response induces a state of ncreased inhibition. Similarly, an inhibitory conditioned reflex creates a tate of increased excitation. When the conditioned excitatory stimulus be pplied immediately after the conditioned inhibitory stimulus, the positive ffects of the former are enhanced. This is called *positive induction*. The everse changes are known as *negative induction*.

Conditioned inhibitory reflexes

Like excitation, a conditioned reflex may also have inhibitory effects. Inhibition may be of two types: (*a*) *external*, and (*b*) *internal*.

External inhibition. *Definition*—A positive conditioned reflex is weakened or inhibited by a simultaneous excitatory process. **Two types:** (*a*) **Temporary.** A sudden noise or fear or any other emotion, distracts the attention of the subject and inhibits the conditioned reflex. Here, *inhibition arises in a part of the brain other than that where the conditioned reflex is initiated.* As soon as the distraction is off, the reflex returns. (*b*) **Permanent.** If the distraction or disturbance be lasting the inhibition may also last long, at least as long as the disturbance persists.

Internal inhibition. *Definition*—The stimulus sets up an inhibitory state in that part of the cerebral cortex which initiates the conditioned reflex. The following types of inhibitory phenomena are seen:

1. **Differential inhibition.** If a conditioned reflex be established with a sound, say, of 800 vibrations per second, tones a little higher or lower, at first acquire some positive conditioned value (*period of generalisation*). If, however, the original stimulus be repeated (reinforced) and not the others, a time comes when the other tones not only become ineffective but exert an inhibitory effect on the primary stimulus (*period of differential inhibition*). For instance, suppose a primary sound produces, say, five drops of saliva. If then a lower or higher tone be applied (unreinforced) just before the primary tone, the effects of the latter will be inhibited and will produce less saliva. Repetition of the allied tones will increase the degree of inhibition (*Summation of Inhibition*).

2. **Extinction by inhibition.** As mentioned above the phenomenon of extinction is due to the development of an inhibitory state in the cortex. Because, during the progress of extinction, other pre-existing conditioned reflexes based on other inborn reflexes are also inhibited.

3. **Conditioned inhibition.** Suppose salivary reflexes are established to the beat of metronome. If then a bell is rung along with the metronome, but is not followed by food, it is seen that the metronome alone will elicit the reflex but metronome *plus* bell is ineffective. The bell sound here acts as *conditioned inhibitor. To have an inhibitory effect, the additional stimulus must overlap the primary stimulus at least to some extent.*

4. **Inhibition of delay.** If the conditioned stimulus be short and be immediately followed by the unconditioned stimulus, the response starts as soon as the conditioned stimulus begins. In other words, the reflex has a short latent period (*Simultaneous reflex*). But if the conditioned stimulus be continued for some length of time (1, 2, 3, etc., minutes), the response comes after the termination of the stimulus, i.e., the latent period lengthens in proportion to the duration of the stimulus.

Functions of conditioned reflexes

(1) Most of our habits are conditioned reflexes. Hence, it is of immense personal and social importance. (2) It has a great applied value in clinical and psychological medicine. (3) With the help of conditioned reflexes cerebral centres can be localised.

Effects of drugs upon conditioned reflexes

1. Caffeine and strychnine increase the effects of positive conditioned stimuli and diminish internal inhibition.

2. Bromide increases internal inhibition.
3. Alcohol, in moderate doses, weakens internal inhibition.
4. Hypercalcaemia (overdose of parathormone or vitamin D) increases inhibitory process and accelerates the extinction of positive or excitatory conditioned reflexes. Caffeine antagonises.

Operant conditioning. Apart from the classical conditionings, this is a form of conditioning in which the animal is taught to perform some task in order to obtain a reward or punishment.

Condition avoidance or avoidance conditioning. If conditioned reflex (CR) is established in an animal by a conditioned stimulus (CS) like bell or light followed by giving a electroshock, then sometimes the animal gives response as for instance moving the leg even before feeling or even application of the second unpleasant stimulus like electroshock. This reflex is developed only to avoid the second unpleasant stimulus. This is known as **condition avoidance.** In Russia it is known as defensive conditioning, conditioning of the second type or type II conditioning.

The operant conditioning differs from the classical and avoidance conditioning in the following features:

1. No specific unconditioned stimulus becomes necessary.
2. The animal is free to respond at any time as per its own will during operant conditioning which rarely occurs in other two varieties

2. Instrumental conditioning or learning

Many years after the development of Pavlovian classical conditioning technique, Konorski (1950) and Skinner (1938) applied the term conditioning to a still different learning procedure. In such procedure an instrument is used. Upon such instrument the animal performs some work and the response or behaviour is termed an instrumental response.

Skinner box (FIG. 5.255) is a versatile instrument of such learning. Another problem box is the maze box which is also used widely. In Skinner box the hungry animal like rat is put and the animal learns how to get a pellet in the food magazine below by pressing the lever. Each pressing is recorded mechanically. In this case food is the unconditioned stimulus (US) and pushing lever is the conditioned reflex or response (CR). It differs from the classical conditioning and avoidance conditioning in that it does not possess any specific conditioned stimulus (CS); and pushing the lever (CR) is not originally an unconditioned reflex (UR) to the food (US).

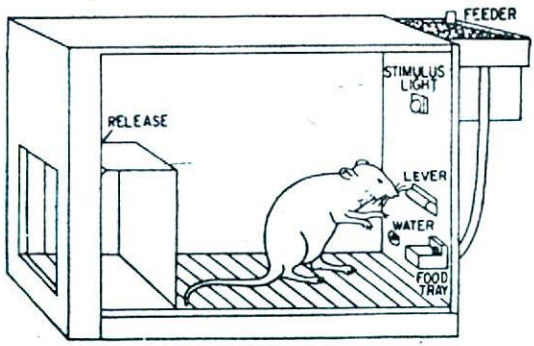


FIG. 5.255. It shows the apparatus which is just big enough to permit free movement of a rat (diagrammatic) used by Skinner in his studies of instrumental conditioning. Cutting away of one side of the chamber in which the animal (rat) is released through the door at the left. As soon as the hungry rat depresses the lever, the apparatus behind the panel at the right automatically releases a pellet of food into the tray from the feeder, or deliver a drop of water.

In maze learning

the animals must learn to make several turns so as to receive a food reward. However, maze learning is a trial and an error learning while the Skinner box learning is a kind of conditioning.

3. Discrimination learning

In addition to the classical conditioning of Pavlov and of instrumental conditioning, animals can learn to differentiate different types of stimuli and can make differential responses. In such discrimination learnings, instrumental learnings are employed and the animals choose between two stimuli presented simultaneously and receive a reward for making a correct choice. Discrimination learning includes (*a*) somaesthetic discrimination, such as (*i*) thermal discrimination, (*ii*) kinaesthetic discrimination, (*iii*) roughness discrimination, (*iv*) form discrimination; (*b*) auditory discrimination, (*c*) visual discrimination.

Physiological basis of conditioned reflexes and learning

Conditioned reflex is the process of learning through the formation of a new functional connection in the nervous system of both cortical and subcortical centres. Repeated application of new sensory stimulus is followed by gradual development of specific cortico-subcortical pathways.

New connections between different organs, centres and neurones are established. During maturation of learning, certain parts of the nervous system as well as the muscle possibly excite some attractive influences on the growth of the new neural fibres and if the new pathway is developed then it is so rigidly fixed that it cannot be abolished so easily. It has been observed that in the mammals there are so many events going on during development of conditioned reflexes and learning. For getting a conditioned response (CR) through both conditioned stimulation (CS) and unconditioned stimulation (US) there require **motivation** and **attention.** An attentive subject learns more earlier than a subject whose attention wanders. Beside this, a hungry rat learns to run a maze for food more readily than a well-fed rat. **Limbic midbrain circuit** of

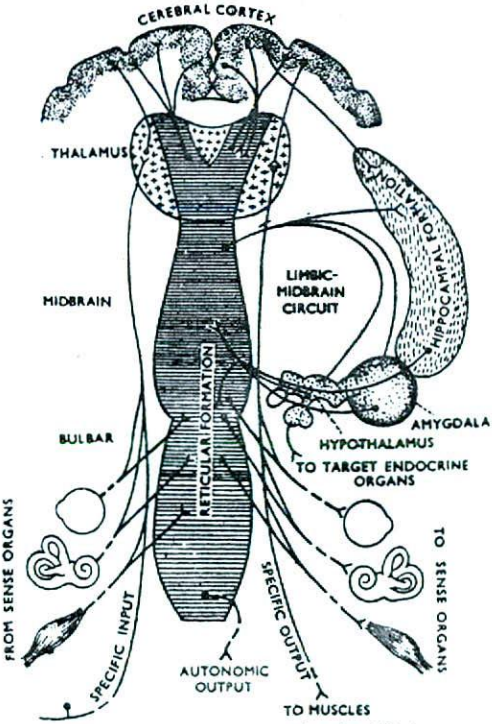


FIG. 5.256. Diagram represents the simplified anatomical plan of neural connections involved during establishment of conditioned reflex or unconditioned reflex (CR or UR) and learning (*after Galambos & Morgan*).

Galambos and Morgan makes a *reverberatory link* in between the limbic system and midbrain reticular formation. The midbrain reticular formation transmits and modifies the impulses to and from the cerebral cortex (Fig. 5.256).

Drugs that facilitate learning

Certain drugs have been proved to help in learning process in animals. Such drugs are caffeine, physostigmine, amphetamine, nicotine, picrotoxin, strychnine and metrazol (pentylenetetrazol). It has been reported that pentylenetetrazol has got effect in improvement of memory in senile human. Pemoline also facilitates learning process in animals. This compound also stimulates RNA synthesis.

MEMORY AND ITS NEUROPHYSIOLOGICAL BASIS

Memory is a special faculty of brain which retains the events developed during the process of learning. Memory may be of two types: **recent memory** and **remote memory.** Recent memory may be lost frequently with neurologic disease but the remote memory is remarkably resistant and may persist even in severe brain damage.

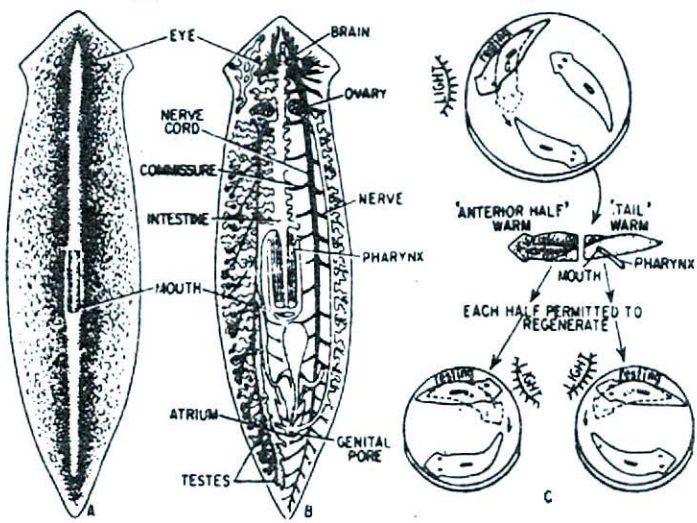


Fig. 5.257. Planarian, a free-living flat-worm. A showing external features and B general structure (diagrammatic), on its right side testes, vas deferens and digestive tract are omitted and on its left side nerve cord, yolk glands and oviduct are omitted. C illustrates regeneration. When exposed repeatedly to bright light at intervals of a minute or so, it will react only to the first few bursts. When exposed repeatedly to mild electroshocks, it continues to react (contract). When such a trained worm is cut in half and each half is permitted to regenerate, both worms react to light, because memory is somehow stored throughout the body.

It is claimed that hippocampus is related with recent memories (*vide* p. 5-173), as because electroshock on the hippocampus causes abolition of recent memories. Bilateral destruction of the hippocampus causes striking defects in recent memories but not of remote memories. Several

drugs that affect recent memories also alter the function of hippocampu considerably.

Regarding permanent memory storage, several explanations hav been put forward on the basis of structural changes. It has been suggested that activation of a synapse during learning process may induce a dendritic growth or new formation of the axonic boutous terminaux, tha strengthens the connections between two neurones.

Other than structural changes, biochemical changes have been suggested in relation to the process of learning and memory. As the remote memory is not lost even after electroshock and brain concussion, it ha been suspected that memory may be stored as an actual biochemica change in the neurones. This fact has come from the work on planarian —the flat-worms having rudimentary nervous system and remarkabl ability to regenerate from cut pieces. These worms can be taught to avoi certain visual stimuli. If these trained worms are cut into two pieces the the regenerated worms from either piece, head or tail can retain previou (learned) response (FIG. 5.257). This has been explained on the basis o changes in RNA of cells. Through the process of learning, there is a stabl change in the RNA which is presumably transferred to the new parts of th regenerated parts. It is further supported that if ribonuclease is adminis tered into the cut pieces of conditioned planarians, then the regenerate planarians cannot retain previous condition response due to destructio of RNA. Besides this, if trained planarians are ground up into powder an fed to untrained planarians then the fed planarians become trained u more earlier than those of the control (unfed) one.

Protein synthesis has got relation with the process of memory an learning. Drugs that inhibit protein synthesis affect the memory an learning. Puromycin which inhibits protein synthesis also disrupts recen memory.

SLEEP

Definition. Sleep and wakefulness occur alternately within 24 hour during whole of the life span of the individual. In spite of tremendou work for unveiling the cause of this natural event, it has not yet bee possible to find out the correct cause of sleep. During sleep, organs lik kidney, heart, lung, gastro-intestinal tract, etc., remain active. Similarl brain also remain active during sleep and it undergoes an active re organisation rather than real inhibition. So it can be assumed as an activ phenomenon. It is also sometimes assumed to be of *passive* phenomenon a the same ensues during withdrawal of the activation process of reticula activating system (RAS) (Moruzzi and Magoun, 1949). Sleep can b **defined** as a state of consciousness that differs from alert wakefulness b a loss of critical reactivity to events in the environment with a profoun alteration in the function of the brain. It is also noteworthy that sleep i not a uniform phenomenon and it varies greatly in nature and depth from time to time in the same person and between individuals as well.

Sleep rhythm. Animals and man show one sleep period in 24 hours Depends on habit. Night, commonly being the period of rest, is used fo sleep. But in night workers, day-sleeping is the habit.

Sleep requirement. Varies inversely with age. For the *new-born baby*—16-20 hours; *children*—12-14 hours; *adults*—7-9 hours; *old age*—5 hours.

Depth of sleep. Follows a characteristic curve. In adults maximum depth at the end of first hour. In children, two maximum periods—one between first and second and the other between eighth and ninth hours. *Deep sleep is not attended with dreams.* Sleep does not affect all the senses equally. Smell and taste are most depressed. Pain, touch and hearing are least affected. Hence, a sleeping man can be more easily aroused by the latter stimuli.

Abnormal wakefulness or *inability to sleep* is called **insomnia.**

Physiological changes during sleep

During sleep somatic activity is greatly decreased. Threshold of many reflexes is elevated and responsiveness is also lessened. Man cannot remember the events occurring during sleep.

Basal metabolic rate being least; all tissues and organs perform the least work. Changes are given below:

1. **Circulatory system.** Pulse rate, cardiac output, vasomotor tone and blood pressure reduced.
2. **Respiratory system.** (*a*) May be costal or periodic, specially in children. (*b*) Tidal volume, rate of respiration and, therefore, pulmonary ventilation—lowered (sometimes rate may be unchanged or even high due to shallow breathing).
3. **Basal metabolic rate.** Reduced by 10–15%.
4. **Urine.** Volume less, reaction variable, specific gravity and phosphates—raised.
5. **Secretions.** (*a*) Salivary and lacrimal—reduced, (*b*) Gastric—unaltered or raised, (*c*) Sweat—raised.
6. **Muscles.** Relaxed (tone minimum).
7. **Eyes.** (*a*) *Eyeballs*—roll up and out—due to flaccid external ocular muscles [May take up any position.] (*b*) *Eyelids*—come closer, specially due to the drooping of the upper lids. (*c*) *Pupils*—contracted.
8. **Blood.** Volume increased (plasma diluted).
9. **Nervous system.** (*a*) *Electroencephalogram*—Appearance of δ-waves. (*b*) *Deep reflexes*—reduced. (*c*) *Babinski*—extensor. (*d*) *Superficial reflexes*—unchanged. (*e*) *Vasomotor reflexes*—more brisk. (*f*) *Light reflex*—retained.
10. **Electroencephalographic changes during sleep.** The EEG pattern changes at different stages from normal waking state to sleep—depending upon the degree of sleep.

(*a*) α-waves gradually diminished in amplitude and per cent. time followed by. (*b*) Further diminution or abolition of α-waves with low voltage fluctuations and occasional δ-waves. (*c*) This stage is characrised by 14 cycles per second spindle bursts associated with low voltage wave background (*light sleep*). (*d*) When δ-wave frequency becomes wer with greater amplitude associated with disappearance of spindle irst (*medium sleep*). (*e*) In this stage, δ-wave becomes more prominent ith higher amplitude and longer duration (*deep sleep*).

The above changes in the EEG pattern occurs sometimes in sequences per (*a*) to (*e*) stages but in between the two, any other stage may supervene during the sleep.

According to the EEG pattern the sleep is divided into *light sleep*, which often associated with rapid wandering eye movement (**paradoxical**

sleep), and is called **rapid eye movement sleep (REM sleep** or **rhombencephalic sleep**) and the other is deep sleep. During REM sleep, high incidence of penile erection and grinding of teeth (**bruxism**) occur in the subjects. On the other hand, non-rapid eye movement (**NREM sleep** or **slow-wave sleep**) is generally associated with **spindle** or **synchronised slow wave.**

Normal sleep with synchronised electrical activity in the thalamus and cortex depends upon **neural and neurohumoral mechanisms**—specially on a **serotonergic substrate**—the raphe nuclei that extend from medulla to midbrain. According to Jouvet, lesions of raphe nuclei reduce normal sleep and partly paradoxical sleep. Concentration of serotonin is found to be increased in midbrain, around the aqueduct and in the hypothalamus during normal sleep.

Effects of prolonged sleeplessness in man. Observed on subjects kept awake for 60–114 hours. *Objective changes are few,* viz., Babinski—extensor. Equilibrium—disturbed, Neuromuscular—fatigue, etc. *Subjective symptoms are chief,* viz., (*a*) Mental concentration difficult and inaccurate. (*b*) Threshold for pain lowered. If very much prolonged, collapse and death. Cortical nerve cells undergo shrinkage and chromatolysis. The lethal period of sleeplessness in man is not known. In dogs it is about 14 days.

Theories of sleep

There are several theories for explaining the cause of sleep, but none is quite competent.

1. **Cerebral ischaemia** (Howell). Sleep is due to cortical ischaemia. The drowsiness after food is due to splanchnic vasodilatation, fall of blood pressure and consequent cerebral ischaemia. Vulpian has shown that after stimulation of the cervical sympathetic in animals cerebral ischaemia was produced but no sleep was induced. But Mangold and Sokoloff (1955) have observed increased cerebral blood flow during sleep. During sleep arterial O_2 content. O_2 consumption remains mostly unchanged.

2. **Pavlov's theory.** Sleep is a special manifestation of *conditioned inhibition.* It is due to spread of an internal inhibitory process and is considered the **concomitant sleep** as a symptom of the cortical inhibition.

3. **Biochemical aspects:**

(*a*) **Acetylcholine** (Dikshit). Since acetylcholine is closely related to the functional integrity of nervous system, sleep is claimed to be due to accumulation of acetylcholine in the cerebral cortex. There is no evidence in support of this theory.

(*b*) **Lactic acid.** Sleep is due to accumulation of lactic acid in the tissues during fatigue. Lactic acid depresses the activities of the cerebral cortex. But in fatigue there is often sleeplessness and oxidation of lactic acid occurs which supplies energy to the brain tissue. So this theory is not acceptable.

(*c*) **Hypnotoxin.** According to some physiologists hypnotoxin which is liberated from the brain tissue, produces sleep. Cerebrospinal fluid taken from a sleeping dog when injected into another dog induces sleep but similar results have been obtained after injection of cerebrospinal fluid taken from a dog kept awake. This theory lacks experimental support.

(*d*) **Bromhormone** (Zondek and Bier). Sleep is induced by the

bromhormone liberated from the 'pituitary. There is no evidence in support of this theory.

Reserpine releases serotonin. If **serotonin** (5-HT) be injected in rabbits, drowsiness is induced initially followed by arousal pattern and mixed relaxation.

5-Hydroxytryptophan (5-HTP) which is a precursor of serotonin, also induces sleep.

Hypnogenic factor (Monnier and Mösli). A hypnogenic factor which is liberated in sleeping donor's blood, induces sleep in a recipient subject. Monnier and Mösli (1965) have observed the liberation of hypnogenic factor in the blood of a sleeping subject. By the process of **haemodialysis,** this extracted factor or blood of the sleeping donor be injected into the vein of the normal free-moving recipient, then it induces sleep.

4. **Kleitman's theory.** Due to reduction of muscle tone and discharge of less afferent impulses, the cerebral cortex remains inactive. Fatigue of the muscle with consequent reduction of transmission of afferent impulses to the cerebral cortex and thereby keeping it inactive seems to be a plausible factor in the production of sleep. Kleitman also observed that reticular formation plays an important role in the production of sleep. The afferent impulses, carried through the peripheral nerves and the spinal cord, activate the reticular formation. Activity of the reticular formation causes *wakefulness*. But in sleep the reticular formation remains inactive. This theory is more acceptable than the others.

5. **Feedback theories of wakefulness and sleep** (*vide* pages 5.188—189).

6. Sleep is a passive process (*vide Central neural mechanisms*).

7. Sleep is an active process (*vide Central neural mechanisms*).

8. **Sleep depends upon conditioned reflex.** Sleep can be described as the activation process of the reticular activating system (RAS). Because certain conditioned stimuli causing activation of reticular formation may induce sleep. Baby is sometimes induced sleep with conditioned stimuli like typical cradle songs, tapping over the head and body, softly brushing the hair and so on. Even in adult certain conditioned stimuli like reading, massaging, brushing, softly pulling hairs, induce sleep.

Central neural mechanisms regulating sleep. Bremer (1953) has observed that animal transected at the level of first cervical segment (encéphale isolé preparation) and keeping blood pressure and respiration normal, then shows the EEG and pupillary signs of normal sleep/wakefulness cycles. He further observed that if transection made at the mesencephalic level, just caudal to the motor nuclei of the III cranial nerve then it caused a permanent condition resembling sleep. This type of preparation is designated as Bremer's cerveau isolé. In cerveau isolé preparation olfactory and visual pathways remain intact. But strong olfactory stimuli produce transient activation. Similarly visual stimulation does not evoke widespread activation of EEG in cerveau isolé preparation with high mesencephalic transection. Thus Bremer concluded tentatively from his observation that deafferentation *per se* is sufficient to induce sleep and also his discovery led to the concept that sleep is passive phenomenon and wakefulness is an active phenomenon maintained by afferent input to the brain. Sleep ensues when that input is removed.

Moruzzi and Magoun (1949) are also in view, from their works, that sleep is a passive process as because if the activation process of RAS (reticular activating system) is withdrawn then sleep ensues. When reticular formation is stimulated in sleeping animals *via* implanted electrodes then different awakening responses along with EEG desynchronisation are observed. This result indicates that the RAS is responsible for wakefulness.

Hess (1952) observed all behavioural signs of normal sleep after slow and rhythmic stimulations (8 per sec.) of the diencephalic region encompassing the thalamic nuclei of generalised thalamocortical system (recruiting system). The animals also show different postures which are normally seen in cats before going to sleep. They also observed behavioural signs of awakening after stimulation of a more ventral and posterior regions, including the posterior hypothalamus and the gray matter at the mesodiencephalic junction. With these observations they came to a conclusion that sleep is an active process because generalised thalamocortical system (recruiting system) influences the activity of the cerebral cells in such a way that sleep ensues.

Moruzzi (1962-63) has also described that sleep may be induced actively by the synchronising influences of the lower brain stem. This lower brain stem is localised at the region of the rostral solitary tract and the adjacent to reticularis ventralis.

The capacity of certain somatic afferents to induce sleep has been studied by Pompeino and Swett (1962-63). They have found that low-frequency stimulation of cutaneous Group II afferents at 10 per sec. cause onset of sleep along with synchronised EEG. But with high-frequency stimulation of the same fibres as well as the Group III afferent cause arousal in sleeping cats.

Desynchronisation of EEG and deep sleep. *Electrical stimulation of the reticular formation* can easily transform a high voltage slow wave (*deep*

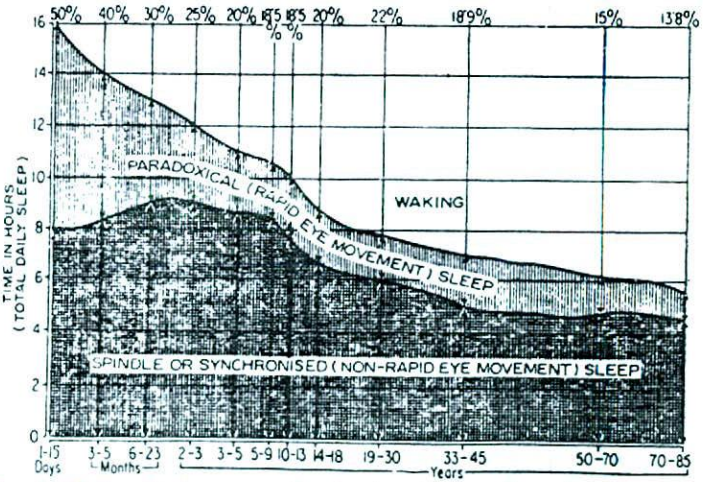


FIG. 5 258. Graphical representation showing changes with age in approximate total amounts of daily spindle sleep, daily paradoxical sleep and in percentage of paradoxical sleep
(after Roffwarg and Others).

sleep) stage to low voltage fast EEG characteristic of the awake or alert animal. This change in the EEG is termed *activation* or *desynchronisation*. The ascending reticular activating system (ARAS) is the controlling system of sleep-wakefulness cycle and is responsible for sleep production (*vide* FIG. 5.182). EEG pattern in deep sleep shows high voltage slow wave (4 per sec.) and somewhat irregular δ-waves. In moderate sleep there are α-like slow wave (10–14 per sec.) with high voltage (50 μV). In paradoxical sleep the EEG pattern of normal sleep is replaced by low voltage and rapid activity. There are rapid eye movement. The paradoxical sleep (RS) is always associated with rapid eye movement and for this reason it is also called REM sleep.

Centre for REM sleep is located probably in the pons. Moderately deep sleep having spindle or synchronised wave pattern in EEG and having no eye movement is designated as NREM sleep. Neural structures responsible for NREM sleep is possibly located at the lower brain stem. Whether these structures belong to medulla or pons or certain serotonergic neurones located at the raphe nuclei are still uncertain.

In total daily sleep REM and NREM occur alternately It has been observed that the decrease of total sleeping hours per day during ontogenetic development of the human is largely due to sparing the period of REM sleep (FIG. 5.258).

EMOTION

It is a kind of psychophysiological phenomenon. It is a multifaceted form of behaviour involving (*i*) different somatic reactions like smiling, laughing, crying, screaming, running in flight and so on, and (*ii*) a variety of autonomic responses like pallor of fear, fainting, decrease or increase of heart rate and so on.

It has been **defined** by neuropathologist, Vonderahe (1944) as follows: "Emotion is a way of feeling and a way of acting. It may be defined as a tendency of an organism toward or away from an object, accompanied by notable bodily alteration. There is an element of motivation—an impulsion to action and an element of alertness, a hyperawareness or vividness of mental processes. There is of course the opposite, a depression of movement."

Emotion has got four aspects, such as (*i*) cognition, (*ii*) expression, (*iii*) experience, and (*iv*) excitement.

1. **Cognition.** It is a such faculty which determines what emotion in kind and degree is appropriated to a given situation. For this, the situation must be perceived in relation to past experience and accordingly evaluated before emotion occurs.

2. **Expression.** It is expressed outwardly in the form of somatic and autonomic activities like facial expression, lacrimation, vocalisation, flashing or paling, laughing, fighting or flight. Emotions are also expressed internally as in the form of visceral and vascular changes by the activities of autonomic nervous system.

3. **Experience.** It is the subjective aspect of emotion. Psychologist divide the experience into two categories by affect, such as (*i*) pleasant, and (*ii*) unpleasant.

4. **Excitement.** It is nothing but an experience or expression of emotion which may be delight or distress.

Besides this, emotion may be classified into three categories, such as pleasure, fear and anger. Fear and anger are disquieting reaction and involve tension and disturbance of the organism's responses, both internal and external.

Fear is a flight or fright reaction and anger is a fight reaction. Pleasure is a quieting or calming reaction; it is practically relief from fear and anger.

While discussing the development of emotion in children, Bridges (1932) has described that first expression of emotion is one of general *excitement*. FIG. 5.259 illustrates the classification of emotional behavior in early childhood in which excitement is the stem from which different kinds of emotions are gradually differentiated. Excitement initially differentiates into distress and delight and each of which is gradually differentiated into as shown in FIG. 5.259.

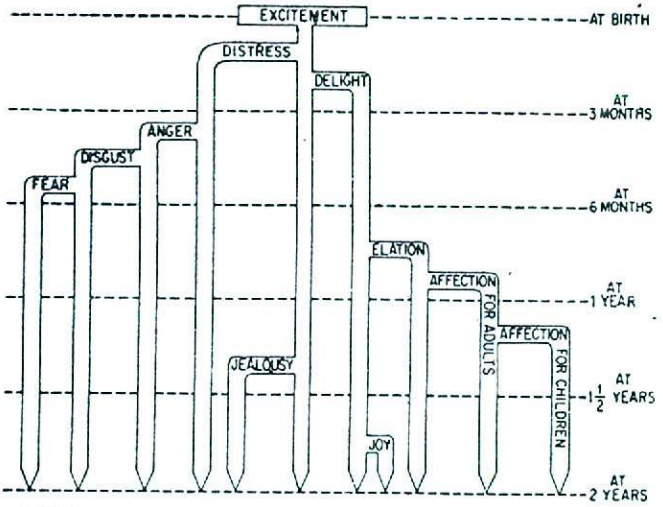


FIG. 5.259. Approximate ages of differentiation of emotion in early childhood (*from Bridges, K.M.B.*, 1942).

Behavioural changes in emotion

In emotion there are different types of behavioural changes. Such changes are somatic reactions which include smiling, laughing, crying, screaming, running in flight, startle responses to sudden loud sounds and other various facial expressions of distress and delight In animals, such somatic reactions are snarling, purring, yelping, tail waging, baring of fangs, hissing and other types of facial and bodily reactions.

In animals and man emotional outbursts are always associated with a variety of autonomic responses. During pallor of fear, blood may tend to leave the head. There is increase and decrease of blood pressure and heart rate. Fainting may be associated with circulatory changes. Glandular secretions may be decreased or increased resulting changes in cellular metabolism. During emotional outburst there is activation of sympathetic and parasympathetic systems. In fear motor activities of

bladder and rectum are increased and these activities are under the control of parasympathetic system. Crying is under the control of parasympathetic.

In emotional disturbance there is often changes in respiration and also profound vasodilatation. Cardiac abnormality leading to death may be associated with emotional stress. These all effects are precipitated due to autonomic imbalance.

Neural control of emotion

Hypothalamus. Hypothalamus is often considered as the seat of emotion. Though this term is misleading, yet hypothalamus is the principal centre in which various components of emotional reactions are organised into definite pattern. It is the focal point for emotional expression as by stimulation of the hypothalamus shows different emotional reactions.

There are evidences that hypothalamus is responsible for elaboration and execution of complex reactions characteristics of anger or rage. This type of rage is excessive in animal having no amygdaloid complex.

Thalamus. It has been observed directly and indirectly that thalamus is also concerned with different emotional reactions and emotional experiences as well. Different areas implicated are (*i*) anterior nuclei, (*ii*) dorsomedial nucleus, and (*iii*) posteroventral nucleus.

Cerebral cortex and limbic system. In earlier experiments, in which total decortication leading to removal of amygdaloid complex was done, animals exhibited profound anger and rage. These facts indicate that cerebral cortex or certain portions of forebrain held in check the mechanisms that are responsible for the bodily expression of anger. It has been observed by Bard and Mountcastle (1947) that decortication, keeping the amygdaloid nucleus intact does not alter the emotional behaviour of the animal (cats and dogs) but as soon as the amygdaloid nucleus on both sides are removed, the animals become furious. This indicate that amygdaloid nucleus exerts an influence which inhibits the activities of brain stem that is concerned with anger and rage.

It has been further observed that projection fibres from the amygdala to the ventromedial nuclei of the hypothalamus, causes inhibition of rage induced by hypothalamus as because selective destruction of ventromedial nucleus of hypothalamus causes calm and quiet animal to a condition of rage.

CEREBROSPINAL FLUID (CSF)

Definition. It is a modified tissue fluid present in the cerebral ventricles, spinal canal and subarachnoid spaces thus bathing the entire nervous system. The central nervous system is devoid of lymphatics. Cerebrospinal fluid replaces lymph here.

Character. It is a *clear*, *colourless*, *transparent* fluid, *does not coagulate* on standing. *reaction alkaline* and contains about 5 lymphocytes per cu. mm. **Sp. gr.**—1·004–1·006. **Volume**—about 150 ml in adults. **Pressure**—110–130 mm H_2O (1 drop per second through the lumbar puncture needle). Pressure rises on standing, coughing, sneezing, crying, etc. Compression of internal jugular veins increases pressure (**Queckenstedt's sign**).

Composition. *Resembles colloid-free plasma* with certain variations of crystalloid content. The average composition is compared with that of plasma is given below.

Proteins—20–30 mgm per 100 ml (*alb/glob* = 1/1)—*much less than plasma.* **Amino acids**—1·5–3·0 mgm per 100 ml—*much less than plasma.* **Cholesterol**—0·06–0·22 mgm per 100 ml—*much less than plasma.* **Glucose** 50–80 mgm per 100 ml—*almost same* or *less than plasma.* **Chloride**—700–750 mgm per 100 ml—*much above plasma* (550–630 mgm per 100 ml). **Sodium**—330 mgm per 100 ml—*same as plasma.* **Calcium**—5·3 mgm per 100 ml (all in ionic form)—*half of the total but same as the ionic calcium of plasma.* **Potassium**—12 mgm per 100 ml—*less than plasma.* **Phosphate** (inorganic)—1·8 mgm per 100 ml—*less than plasma.* **Sulphate**—0·6 mgm per 100 ml—*less than plasma.* **Magnesium**—3·0–3·6 mgm per 100 ml—*more than plasma.* **Bicarbonate** (CO_2—volume per cent.)—40–60 mgm per 100 ml—*same as plasma.* **Urea**—10–30 mgm per 100 ml—*almost same or slightly less than plasma.* **Uric acid**—0·5–2·2 mgm per 100 ml—*less than plasma.* **Creatinine**—0·5–2·2 mgm per 100 ml—*almost same.* **Lactic acid**—8–27 mgm per 100 ml—*less than plasma.*

Bile pigments are not usually present. But in severe jaundice of long duration they are found in the cerebrospinal fluid. Certain drugs, bacteria and toxins do not freely pass. In certain diseases of the central nervous system, characteristic changes take place in the cerebrospinal fluid. They are of great diagnostic value.

Formation of cerebrospinal fluid

Site of formation. Formed by *choroid plexuses* in the ventricles, specially the lateral ventricles. Choroid plexuses are tuft of capillaries covered by ependyma. The endothelial cells of the capillaries are not flat as elsewhere, but are *granular* and *cubical* with *mitochondria* and *vacuoles. This arrangement indicates active metabolic processes in the cells.* Hence, not a passive filter.

Rate of formation. As seen with lumbar puncture, the rate in adults is about 20 ml per hour or 500 ml per day.

Mechanism of formation

Two theories: (1) **Filtration**—plays a minor rôle. (2) **Secretion**—this is the main process. Following observations show that it is mainly a secretion:

(*a*) Available filtration pressure—very little. The probable figures are as follows:

1. Blood pressure in the capillaries of choroid plexus is not exactly known. Let us assume it to be 30 mm of Hg as elsewhere.
2. Colloidal osmotic pressure of plasma—25 mm of Hg as elsewhere.
3. Pressure of the cerebrospinal fluid in the ventricles—about 5–10 mm of Hg (in the tissue spaces generally it is 0).

Available filtration pressure is therefore 0 to 5 mm of Hg. Hence, from this calculation, filtration does not seem to be possible.

(*b*) Crystalloid composition not identical with plasma. (*c*) Radioactive elements, after administration, do not show identical concentration in plasma and cerebrospinal fluid. (*d*) Experiments show that active work is done by the choroid plexuses. (*e*) Histological features of the endothelium suggest active secretion.

Circulation. From the lateral ventricles (first and second) the fluid passes through the foramina of Monro (right and left interventricular foramina) to the III ventricle, thence through the midbrain as aqueduct

Within the cranium the CSF flows upwards through the gr
on the hemisphere cerebelli & then forwards & laterally over the inf
surface of the cerebrum. Finally it ascends the superolateral aspect of
each hemisphere to reach the arac. villi associated with S.S. sinus,
able to pass back again into the blood stream.

of Sylvius (cerebral aqueduct) to the IV ventricle in the medulla. From the IV ventricle the fluid follows three routes—central one the foramen of Magendie ending directly into the *cisterna magna* and two lateral ones, the foramina of Luschka ending into the *cisterna pontis* on the basal aspect of the brain stem to the subarachnoid space. From the IV ventricle it also passes into the central canal of the spinal cord (FIG. 5.260). The ciliary movements of the ependymal cells help in the circulation of the cerebrospinal fluid.

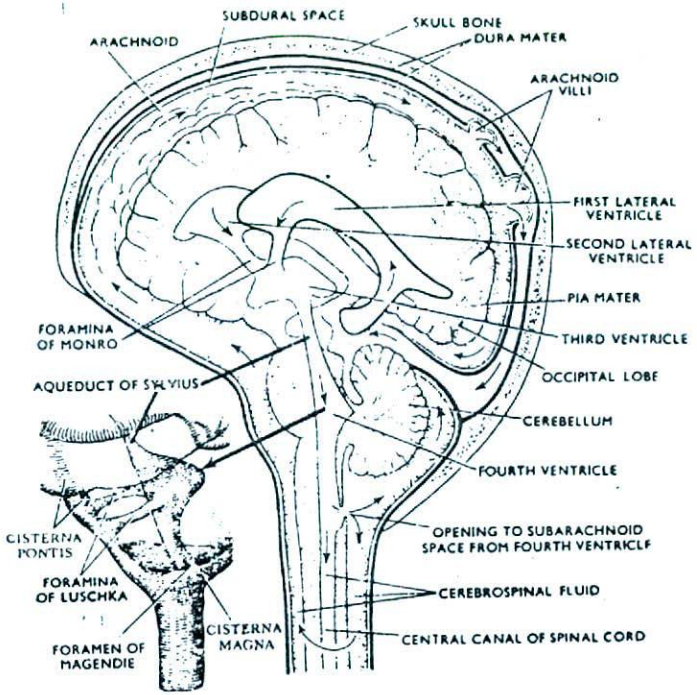


FIG. 5.260. Ventricles of the brain and the central canal of the spinal cord (lateral view) through which the cerebrospinal fluid circulates.

Flow of cerebrospinal fluid down the spinal canal has been demonstrated by Bradbury and Lattern (1965) in rabbit. Dye, injected into the lateral ventricle, appears rapidly at all places along the canal and later is found in the spinal subarachnoid space.

Nervous and humoral factors controlling the formation and circulation of the cerebrospinal fluid. Numerous nervous and humoral factors are concerned in the formation and circulation of cerebrospinal fluid. Sympathetic stimulation alter the formation and circulation of cerebrospinal fluid. The stimulation of the cervical sympathetic nerve reduces the production and pressure of the cerebrospinal fluid by increasing the tonus of the pial vessels.

Chloroform, ether, chloral, alcohol all stimulate in the production of cerebrospinal fluid, whereas the posterior pituitary extract and caffeine

reduce its formation. Hypertonic glucose solution also decreases the cerebrospinal fluid pressure.

Absorption. Absorbed into the cranial venous sinuses through the **arachnoid villi.** Small amounts are absorbed by the perivascular spaces and the spinal veins. Arachnoid villi are small finger-like processes projecting into the venous sinuses. The larger ones are called *pacchionian bodies* or *arachnoidal granulations.* Clumps of specialised cells, known as **Meningocytes** are found in the arachnoid villi (also abundant in the lining of the subarachnoid space) (FIG. 5.260). They belong to the reticuloendothelial system and act as phagocytes.

Mechanism of absorption

Two factors: (1) **filtration** and (2) **osmosis.**

1. **Filtration.** Pressure of the cerebrospinal fluid is higher than that of venous blood in the cranial sinuses. Hence, the cerebrospinal fluid is filtered out into the veins.
2. **Osmosis.** Colloidal osmotic pressure of plasma is 25 mm of Hg. That of the cerebrospinal fluid is negligible. Hence, cerebrospinal fluid is drawn into the sinuses.

Functions of cerebrospinal fluid

1. **Mechanical buffer.** Remaining inside and outside the central nervous system it equalises mechanical pressure, thus acts as cushion between the soft and delicate brain substance and the rigid cranium. Any change of pressure is equally distributed and thus mechanical injury is prevented. If intracranial pressure tends to rise, cerebrospinal fluid is pressed out. If the pressure tends to fall, more cerebrospinal fluid is retained.
2. **Drainage of metabolites.**
3. **Nutrition and O_2 supply** to the nerve cells to some extent (they are supplied mainly directly from the blood).

Lumbar puncture

Cerebrospinal fluid can be collected from the subarachnoid space by introducing a special needle between the third and fourth lumbar spines. This procedure is called *lumbar puncture.* This lumbar puncture technique is of great clinical importance for *diagnostic purposes* of meningitis, increased intracranial pressure, syphilis, intracranial tumours and cerebral haemorrhage and for *therapeutic purposes* of relieving pressure in meningitis, convulsions in children, hydrocephalus and rarely for introduction of sera, i.e., antimeningitis serum or drugs and for spinal anaesthesia.

Ventriculography

The size, shape, position, etc., of the ventricles can be studied under X-ray—after injecting air or a radio-opaque substance, viz., *thorotrast,* into the lateral ventricle (3·0 ml thorotrast in each lateral ventricle) by a fine needle introduced through a trephine hole and passing through the silent area. Equivalent amount of cerebrospinal fluid is withdrawn before introduction of thorotrast. This is of considerable clinical help in certain diseases of brain, e.g., in the localisation of *cerebral tumours.*

Hydrocephalus

It is due to abnormal accumulation of cerebrospinal fluid. It occurs due to any of the following factors.

1. Increased secretion of the cerebrospinal fluid which gives rise to symptoms of pressure, viz., headache, slow pulse, slow respiration and complete or partial unconsciousness.
2. Obstruction in the passage of the cerebrospinal fluid, e.g., in the foramina of Monro, or in the aqueduct of Sylvius, or in the IV ventricle, or in the foramina of Magendie and Luschka.
3. Retardation of absorption of the cerebrospinal fluid through the arachnoid villi.

Hydrocephalus may be internal or external. In *internal* hydrocephalus the circulation of cerebrospinal fluid if blocked, the fluid accumulates within lateral and III ventricles. Whereas in *external* hydrocephalus the fluid accumulates in the subarachnoid space around the brain due to blockade of cerebrospinal fluid drainage from the subarachnoid space.

Effects of injection of isotonic, hypotonic and hypertonic saline solution

1. Intravenous injection of isotonic saline solution causes transient rise of cerebrospinal fluid pressure and venous pressure.
2. Intravenous injection of hypotonic saline causes prolonged rise of cerebrospinal fluid pressure along with increased venous pressure. Due to diminution of crystalloid osmotic pressure of the plasma, water flows from the plasma into the interstitial space where the crystalloid osmotic pressure is higher. So water flows from the plasma into the cerebrospinal fluid and there is rise of cerebrospinal fluid pressure.
3. Intravenous injection of hypertonic saline solution causes marked fall in cerebrospinal fluid pressure along with slight initial rise of venous pressure. Due to raised crystalloid osmotic pressure of the plasma, fluid is drawn from the cells into the interstitial fluid and from the latter into the plasma, i.e., from the brain into the cerebral blood vessels. The convolutions become smaller due to shrinkage of the cerebral tissue. Due to increased osmotic pressure in the cerebral blood vessels cerebrospinal fluid is withdrawn into the latter and flow of cerebrospinal fluid is reversed.

BLOOD-CSF AND BRAIN BARRIER (FIG. 5.21)

The composition of the cerebrospinal fluid mostly depends upon the nature of flow of materials from the perivascular spaces into the fluid spaces and *vice versa* through diffusion. Therefore an exchange of materials between the intracellular fluids of brain parenchyma and the cerebrospinal fluids and *vice versa* will also alter the fluid composition. The knowledge of the nature of transformation of different materials from the blood to the cerebrospinal fluid and thence to the brain parenchyma and *vice versa* is not only of great academic interest but also of clinical importance. Because certain materials can diffuse through spaces but others do not. Generally it is assumed that there are the existence of three barriers: (*a*). blood-cerebrospinal fluid barrier, (*b*) blood-brain barrier, and (*c*) cerebrospinal fluid-brain barrier.

1. **Blood-cerebrospinal fluid barrier.** The transfer of materials from the blood into the cerebrospinal fluid apparently takes place very slowly, because there is a blood-cerebrospinal fluid barrier. A lepoid soluble substances may pass from the blood to the cerebrospinal fluid more easily than a less lepoid soluble material. Ions, active compounds

and drugs alter the brain-cerebrospinal fluid barrier. Epinephrine and calcium decreases the permeability of the above barrier. Theophylline, on the other hand, increases the permeability of the blood-cerebrospinal fluid barrier.

The blood-cerebrospinal fluid barrier is associated mainly with the endothelia of the choroid plexus and also in part with those of the meningeal capillaries of the pia.

2. **Blood-brain barrier.** The blood-brain barrier is a controlling mechanism existing hypothetically as **membrane-barrier system** which allows selectively some substances from the capillary blood to enter the brain. Its exact anatomical entity has not been clear, but it can be easily demonstrated to exist by administering certain dyes (trypan blue) into blood which will stain most of the body tissues *except the nerve tissue of the brain and spinal cord.* Endothelium of the vessels with its basal membrane and astroglia are presumably involved in functioning of the blood-brain barrier.

Morphological characteristics of blood-brain barrier shows (*a*) the high electron density of endothelial cytoplasm, (*b*) thicker basement membrane, (*c*) absence of perivascular connective tissue, (*d*) complete covering of the endothelial surface by astrocytic processes, and (*e*) small number or absence of cytoplasmic vesicles in endothelial cells.

Morphologically, blood-brain barrier is constituted by the layer of astrocytic end feet. Lateral zonulae occludentes of the capillary endothelium force solutes to pass through the cytoplasm of astrocyte which restrains the passage of molecule through its plasma membrane.

In physical or traumatic injuries of the brain, vascular damage or some types of neural disorders like brain contusion or epilepsy, the permeability of the barrier is increased. Water, CO_2, O_2 cross the blood-brain barrier (BBB) readily, glucose appears to be actively transported, while Na^+, K^+, Mg^{++}, Cl^-, HCO_3^- and HPO_4^- pass very slowly in comparison with other non-neural interstitial space. Bile salts, epinephrine, serotonin normally cannot pass the blood-brain barrier (BBB) except in very minute amounts. Proteins cross the barrier to a very limited extent. Acidic dyes penetrate more slowly than basic ones, but positively charged ions penetrate with difficulty. Drugs like antibiotics—penicillin, tetracycline, cannot pass the blood-brain barrier while sulphadiazine enter quite readily.

Certain factors may alter the blood-brain barrier. Lowering of brain pH or increasing of blood pH enhances the capillary permeability in the blood-brain barrier. O_2 lack also raises the permeability of the blood-brain barrier.

The blood-brain barrier maintains the constancy of the environment of the neurones in the central nervous system in such a way that the multiple homeostatic mechanism of the ionic transfer during neuronal activity is maintained.

3. **Cerebrospinal fluid-brain barrier.** The cerebrospinal fluid-brain barrier is located in the layer of glial fibres lining the outer surface of the brain or in ependyma that lines the ventricles. Between the cerebrospinal fluid and brain the exchange rate is faster than its exchange across the cerebral capillaries of choroid plexus. But water-soluble materials of large molecular weight cannot pass easily the cerebrospinal fluid-brain barrier.

AUTONOMIC NERVOUS SYSTEM

General considerations. Autonomic system is that part of nervous system which controls the activity of viscera. Its actions are generally unconscious and independent of 'will'. Consequently, the motor processes are all reflex actions. *Control by the autonomic system is mostly homolatera.* Like the somatic system it has got a spinal and a cranial outflow. Certain special nerve centres situated in the medulla, pons and midbrain are included in this system. Also other higher centres like hypothalamus, thalamus, corpus striatum and cerebrum—control this system. This activities of the somatic and autonomic system always run parallel. Because, at each important level of the nervous system, there are free intercommunications between these two systems. Cerebrum controls both these systems. Although involuntary, yet the system is not altogether beyond voluntary control.

I. Classification — can be classified in three ways :

1. **Anatomical.** According to the situation of outflow :
   (*a*) **Craniosacral** (cranial [tectobulbar] III, VII, IX, X and sacral —2 —4).
   (*b*) **Thoracolumbar** (thoracic 1-12 and lumber 1—3).
2. **Functional.** According to the nature of function.
   (*a*) **Sympathetic** — same as thoracolumbar.
   (*b*) **Parasympathetic** — same as craniosacral.

The parasympathetic reactions are usually localised reactions and the sympathetic reactions are concerned with mass reactions. The parasympathetic activity results for instance, in slowing of the heart and increase in the peristaltic and glandular activities of the gut ; these conserve the body energies. Sympathetic activity results, for example, in constriction of the cutaneous arteries (with consequent increase in the blood supply to the heart, brain and muscle), acceleration of the heart and increase of blood pressure, contraction of the sphincters and lessening of the peristalsis of the gut ; these mobilise body energies for dealing with emergencies.

These two are functionally opposite. Broadly speaking, functions of

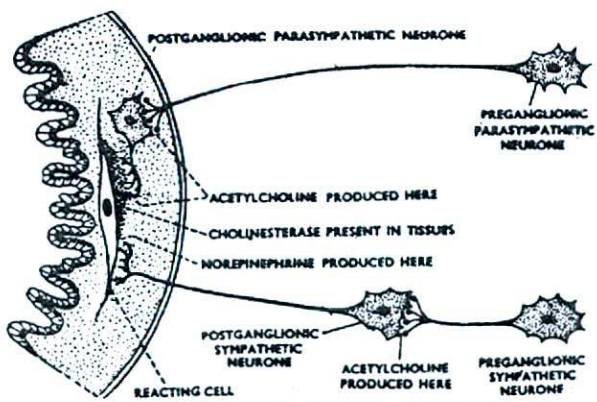


FIG. 5.261 Diagrammatic representation of cholinergic fibres which release acetylcholine at their terminals and adrenergic fibres those release norepinephrine (*noradrenaline*) and some epinephrine (*adrenaline*) at their terminals.

sympathetic are *catabolic*, while those of parasympathetic are *anabolic* in nature.

3. **Chemical.** According to the chemical substances liberated (FIG. 5.261).

(*a*) **Adrenergic.** Those producing norepinephrine or epinephrine at the nerve endings. Include only the postganglionic fibres of sympathetic except to sweat glands.

(*b*) **Cholinergic.** Those producing acetylcholine. Include (*a*) the whole of parasympathetic—both preganglionic and postganglionic fibres. (*b*) all preganglionic sympathetic fibres, and (*c*) those postganglionic sympathetic fibres which supply the sweat glands.

It is to be noted that the adrenergic fibres produce epinephrine or norepinephrine at the nerve endings, whereas cholinergic fibres produce acetylcholine both at the synapses (ganglia) as well as at the nerve endings.

The parasympathetic receptors may be excitatory, as in glands and in smooth muscle cells of the alimentary canal, or inhibitory, as in the heart. Sympathetic β-receptors in blood vessels (when present) are not innervated, but in other kinds of receptor cell, such as the heart, they are thought to be innervated and may be excitatory.

II. **General arrangement** (FIG. 5.262). Autonomic reflexes are very important in the control of the viscera. Like some of the somatic reflex arcs the autonomic reflex arc also contains three neurones, e.g., *afferent*, *connector* and *efferent* (excitor or effector) neurones. In the somatic system the afferent neurones lie in the posterior root ganglia (or their cranial homologues). In the autonomic system they also lie in the posterior root ganglia. The connector neurones in the somatic system are found in the posterior horn cells. But in the autonomic system they are found in the lateral horn cells In the somatic system the effector neurones are situated in the anterior horn cells. But in the autonomic system they are not present in the central nervous system at all. They lie outside the central nervous system in the form of various ganglia. *The presence of peripheral ganglia is the characteristic feature of the autonomic system. In the sympathetic system the ganglia lie away from viscera supplied. But in the parasympathetic system they lie in or near the viscera* (exception—Meckel's ganglion and otic ganglion). Hence, the parasympathetic system exerts a more localised action than the sympathetic system.

Autonomic functions like the control of the elasticity of blood vessels, sweating, gastro-intestinal, genito-urinary, respiratory and cardiac functions are reflexly maintained. **Autonomic reflexes** are qualitatively similar to somatic ones and mostly they are polysynaptic. However, because of the interneurone located in the spinal cord, the integrity of the spinal cord is essential for regulating the autonomic reflex arcs.

Functional significance. Efferent postganglionic fibres that run in gray rami communicantes to the spinal nerves innervate vasoconstrictor fibres to blood vessels, motor fibres to the arrectores pilorum muscles in the areas supplied by the corresponding spinal nerves, and secretomotor fibres to the sweat glands. Those efferent postganglionic fibres accompany motor nerves to voluntary muscles are presumably distributed only to blood vessels supplying the muscles. Those fibres which run in the viscera and other structures are related to vasoconstriction, dilatation of pupils and of bronchioles, movements of the alimentary tract and the urinary bladder

(relaxation of muscle walls and contraction of sphincters), glandular secretion, and so on. A certain preganglionic fibre synapses with the postganglionic neurones supplying one effector system only, a dissociation of sympathetic actions, viz., vasomotor and sudomotor activities, can take place. While the actions of the sympathetic and parasympathetic systems are generally antagonistic on the viscera they supply, in the case of the urinary bladder, for example, the normal emptying and filling

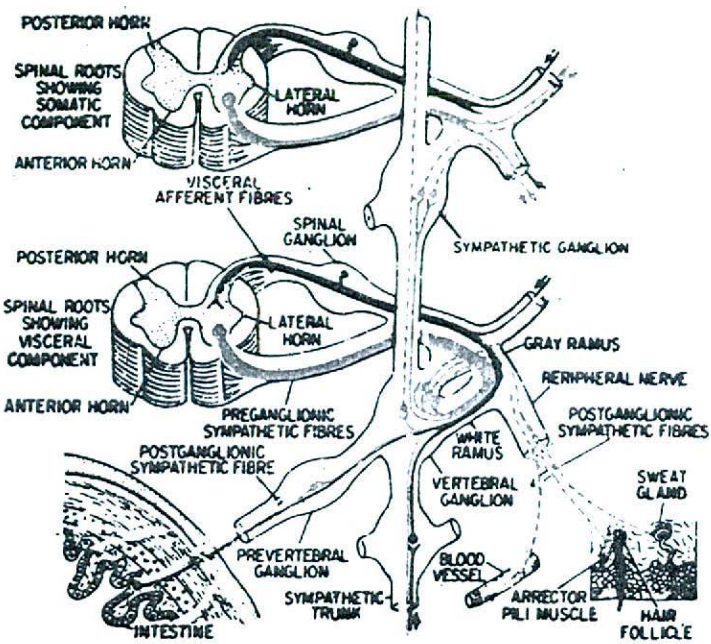


FIG. 5.262. It shows the constitution of a typical spinal nerve. The upper part shows the somatic components and the lower part, the visceral components. *Red solid lines* representing motor efferent somatic and preganglionic visceral fibres; *black solid lines* indicating afferent somatic and visceral fibres; *red dotted lines* showing postganglionic visceral fibres.

of the viscus are controlled only by the parasympathetic system, the sympathetic system being concerned with blood supply of the organ. Some of afferent sympathetic fibres mediate pain impulses. On the other hand, afferent parasympathetic fibres are concerned with visceral reflexes which operate under normal conditions of life. In most cases afferent sympathetic fibres are probably concerned with unusual or pathological reflexes.

III. **Dual supply.** Most of the organs in the body are supplied both by sympathetic (*thoracolumbar*) and parasympathetic (*craniosacral*) nerves, exerting antagonistic actions. But some structures are supplied by sympathetic alone, e.g., adrenal medulla, most arterioles, ureters, uterus, Fallopian tubes, seminal vesicles, etc. While there are certain other structures having parasympathetic supply alone, e.g., oesophagus, gastric glands, pancreas including the islets of Langerhans, lacrimal glands, etc.

IV. **Drugs acting on autonomic nervous system** (FIG. 5.263).

ON SYMPATHETIC:

1. **Epinephrine and norepinephrine.** Sympathomimetic (*vide* Chapter 4).
2. **Ephedrine.** Augments epinephrine action.
3. **Cocaine.** Augments sympathetic action (hence, also of epinephrine).
4. **Ergotoxin.** Small doses stimulate but large doses paralyse the motor constrictor and secretory sympathetic fibres. Has no action on sympathetic inhibitors.

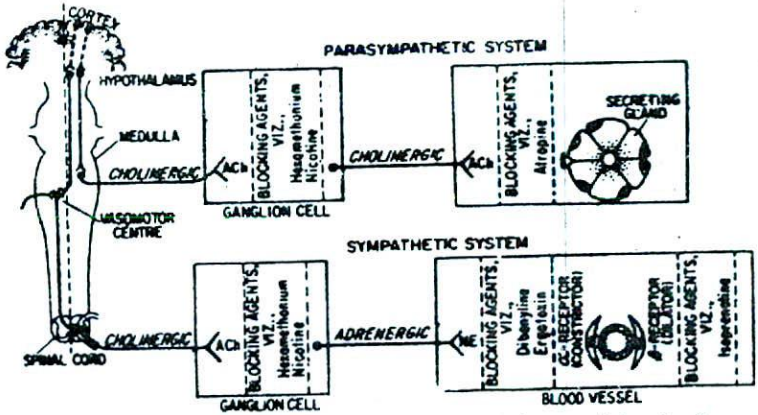


FIG. 5.263. Schematic representations of chemical transmission in the autonomic nervous system and distribution of cholinergic and adrenergic neurones, where a secreting gland is taken as a typical effector organ innervated from the parasympathetic system; and the smooth muscle in a blood vessel as a typical effector organ innervated from the sympathetic system.

ON PARASYMPATHETIC:

1. **Acetylcholine.** Parasympathomimetic (*vide* 'Acetylcholine')
2. **Eserine and prostigmine.** Augment acetylcholine action. Hence, action same as parasympathetic stimulation.
3. **Pilocarpine and muscarine.** Stimulate parasympathetic.
4. **Atropine.** Prevents acetylcholine action. Hence, 'paralyses' parasympathetic.

ON BOTH:

1. **Nicotine.** Acts on the ganglion. At first stimulates (small doses), then paralyses (large doses) all autonomic synapses.

V **Methods of study**

1. **Effects of stimulation.** (*a*) *Of sympathetic:* Same as epinephrine action (*vide* Chapter 4). Action on the *eye* is specially mentioned here (*i*) Dilatation of pupil, (*ii*) retraction of both lids (specially the upper in man) thus widening the palpebral fissure. This gives a false impression of exophthalmos. (*b*) *Of parasympathetic.* [*Vide* Parasympathetic action discuss latter.]
2. **Effects of extirpation.** (*a*) *Of sympathetic:* (*i*) Animals after bilateral removal of vertebral chains (Cannon) maintain blood pressure

and body temperature within normal range under resting laboratory conditions, but show limited compensation against exercise, haemorrhage, cold, anoxia, etc. (*ii*) In man section of cervical sympathetic produces *Horner's syndrome*, e.g., (1) constriction of pupil (overaction of third cranial nerve), (2) narrowing of palpebral fissure due to drooping of eyelid (ptosis). (*b*) *Of parasympathetic*—reverse of stimulation.

3. **Histology, course, distribution and function** of autonomics.
4. **Action of drugs** on autonomics (*vide* page 5-281).
5. **Study of action potentials** in the autonomic nerves.

Structure of autonomic ganglia (Fig. 5.264). The autonomic ganglia are cellular aggregations of varying size and shape, each surrounded by a connective tissue capsule. Trabeculae extending from the capsule constitute an internal framework which contains numerous, often pigmented cells, between which are irregular plexuses of myelinated and unmyelinated fibres. Besides these ganglia, there are the isolated autonomic cells or non-encapsulated aggregations of such cells widely distributed throughout the viscera.

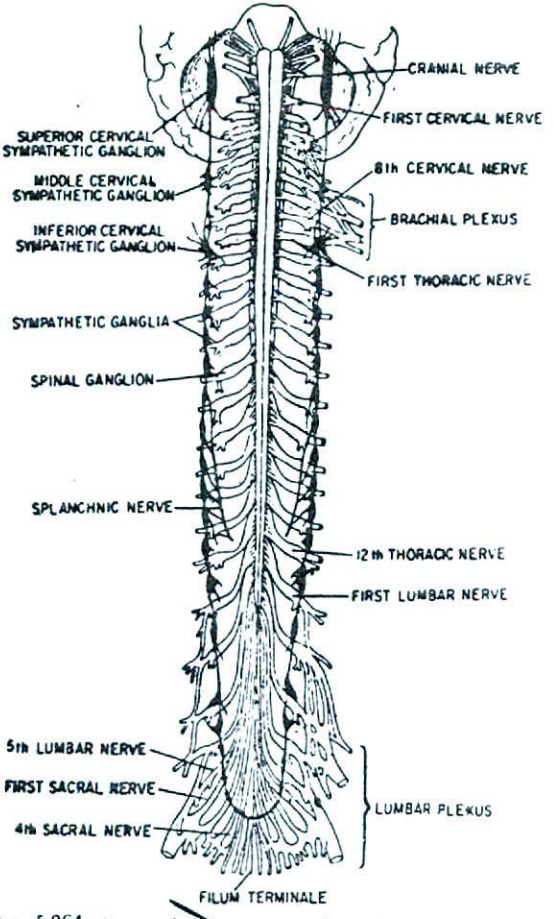


Fig. 5.264. Anatomical representation of spinal cord, spinal nerves, right and left chains of the autonomic ganglia (diagrammatic).

The autonomic cells are typically multipolar in shape and have a clear spherical or ovoid nucleus, delicate neurofibrils, and fine chromophilic bodies. Binucleated or even multinucleated cells are also found. Most of the cells are surrounded by cellular capsules similar to those surrounding the spinal ganglion cells.

In the autonomic ganglia of man, some of the cells commonly have short dendrites which ramify within the capsules. Others have long, slender dendrites which pierce the capsule and run for varying distances in the intercellular plexuses. Some cells have both short and long processes. The intracapsular

dendrites may arborise symmetrically on all sides of the cell or they may form *glomerular* structures on one side. These *glomeruli* are generally formed by the interlocking dendritic processes of two or more cells, and all the cells so interlocked are enclosed within a single capsule (Fig. 5.265). Such cells presumably receive common terminal arborisations of preganglionic fibres. The extracapsular dendrites terminate in similar end arborisations at varying distances from the cell body.

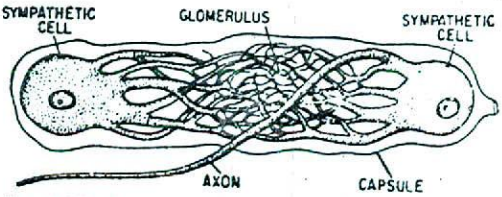


Fig. 5.265. Diagrammatic representation of glomerulus formed by the dendrites of two sympathetic cells (*after Cajal*).

Numerous preganglionic fibres end in synaptic relation with the bodies and dendrites of the postganglionic cells. They branch repeatedly within the ganglion and form pericellular arborisations, the terminal fibrils ending by neurofibrillar rings or loops on the cell body.

SYMPATHETIC (THORACOLUMBAR) SYSTEM

As mentioned before, sympathetic outflow takes place from the thoracic and lumbar regions. *The connector cells lie in the lateral horn cells situated only in the thoracic and upper three lumbar segments* (T. 1 to L. 3.). In the cat, dog and monkey sympathetic fibres are also found in the anterior root of the lumbar segment 4. Since the effector neurones lie outside the central nervous system, the axons of the lateral horn cells of the spinal cord (intermediate lateral tract) pass out through the anterior root and enter the anterior divisions of the mixed spinal nerve. These fibres are thinly *medullated* (β), hence white. They leave the nerve in the form of a branch called the **white ramius communicans** and enter the sympathetic ganglion. It may end in this ganglion or may simply pass through it to other ganglia up or down the sympathetic chain or even to other distant ganglia. The effector fibres (postganglionic) arising from the ganglion of sympathetic chain are non-medullated, hence gray. They run back to join the spinal nerve in the form of another branch called the **gray ramus communicans,** and are ultimately distributed either along the blood vessels or the spinal nerves. It is to be noted that all the spinal nerves possess *gray rami*, but only the thoracic and lumbar nerves have *white rami*.

As noted before, the cell bodies of the afferent neurones lie in the posterior root ganglia or their cranial equivalents. The dendrites collect impulses from the viscera, pass through the white ramus and end in the cell body. The axons transmit impulses to the lateral horn cells (Fig. 5.262).

Sympathetic ganglia. Three classes of sympathetic ganglia:

1. **Vertebral ganglia.** Consist of about twenty-two ganglia, lying by the side of the vertebral bodies and connected together by nerve fibres in the form of a chain. It extends from the base of the skull to the front of the coccyx. As a rule, there is one ganglion for each segment. But they show a tendency to coalesce (Fig. 5.264) For instance, the eight cervical ganglia become fused into three—the **superior, middle** and **inferior cervical ganglia.** In the thoracic region there are from ten to twelve ganglia on each side. The first thoracic ganglion in man sometimes fuses

with the inferior cervical ganglion forming the **stellate ganglion.** In the lumbar region there are usually four. In the sacral, four to five, which in the coccygeal region the terminal portions of the two sympathetic chains fuse together and form a single ganglion in front of the coccyx **(coccygeal ganglion).**

2. **Collateral ganglia (Prevertebral ganglia).** Lie in the thorax, abdomen and pelvis in close relation with aorta and its big branches. For instance, the **coeliac** (solar or semilunar), **superior mesenteric, inferior mesenteric,** etc.

3. **Terminal ganglia.** They are situated in close relation to organs of supply.

SYMPATHETIC OUTFLOW

I. **Head and Neck.** *Connectors* (preganglionic)—T. 1 and T. 2. *Effectors* (postganglionic)—superior cervical ganglion.

1 **Eye.** Postganglionic sympathetic fibres pass from the superior cervical ganglion to internal carotid artery (*internal carotid plexus*) and ophthalmic artery to the orbit. Supply—(*a*) Vessels of eyeball, retina, ciliary body and dilator muscle of the pupil (dilatation of pupil). (*b*) *Smooth muscles* of the upper and lower lid (retraction of lids). (*c*) The *retro-ocular plain muscles* of Müller (protrusion of eyeball). In man the latter is rudimentary.

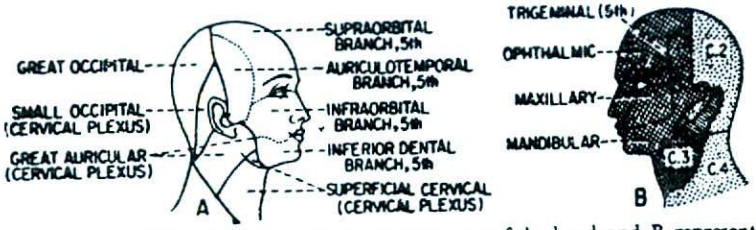


FIG. 5.266. A shows the distribution of sensory nerves of the head and B represents lateral view of skin areas innervated by fifth cranial nerve and second, third and fourth cervical segments.

2. **Skin structures.** Postganglionic sympathetic fibres pass from superior cervical ganglion to upper 4 cervical nerves (FIG. 5.266). join the brachial plexus and finally pass along the cutaneous nerves. From the skin of the face they pass along the branches of external carotid artery. Throughout the whole body, the skin structures supplied by the sympathetic are (*a*) *sweat glands*—secretory fibres (*cholinergic*), (*b*) *plain muscles*—arrectores pili (which erect hairs and produce an appearance in man as goose skin) those around the orifices of the body (anal sphincters and vagina), retractor penis, dartos, etc. (*c*) *blood vessels*—vasoconstrictors, may be some vasodilators.

3. **Glands.** (*i*) Buccal, parotid, sublingual, submaxillary (submandibular) and lacrimal glands receive both *vasoconstrictor* and *trophic sympathetic fibres* along the blood vessels. (*ii*) **Thyroid**—from middle cervical ganglion along the blood vessels, probably vasomotor.

4. **Cerebral blood vessels.** From superior and inferior cervical ganglia passing along internal carotid and vertebral arteries respectively.

II. **Thoracic viscera.** *Connectors* from T. 3 and T. 4. *Effectors* from the three cervical ganglia.

1. Heart—acceleration.
2. Coronary vessels—dilatation.
3. Bronchial muscles—relaxation. Bronchi dilate.
4. Pulmonary vessels—constriction.

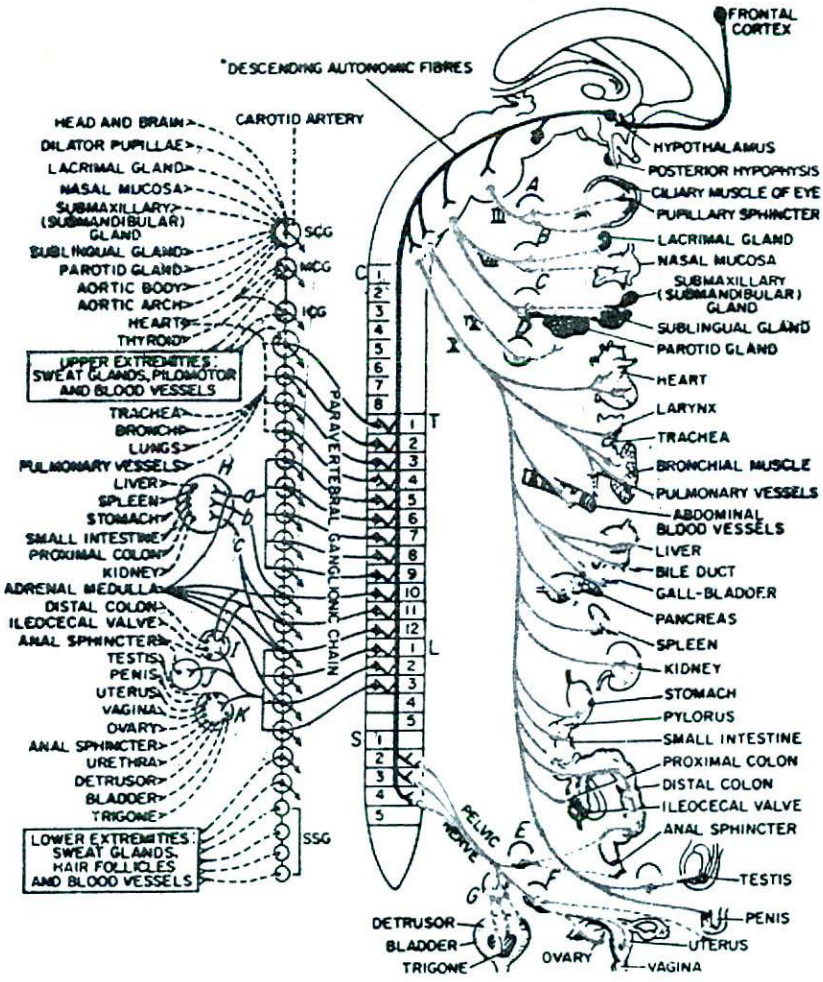


FIG. 5.267. Diagrammatic representation of the autonomic nervous system.
Black solid lines designate *pre*ganglionic sympathetic fibres; *Black dotted lines* represent *post*-ganglionic sympathetic fibres. *Red solid lines* show *pre*ganglionic parasympathetic fibres; *Red dotted lines* indicate *post*ganglionic parasympathetic fibres.

A=Ciliary ganglion, *B*=Sphenopalatine ganglion, *C*=Submaxillary (submandibular) and sublingual ganglion, *D*=Otic ganglia, *E* & *K*=Hypogastric plexus, *F*=Inferior hypogastric plexus, *G*=Vesical plexus. SCG=Superior cervical ganglion, MCG=Middle cervical ganglion, ICG=Inferior cervical ganglion, SSG=Sacral sympathetic ganglion, *H*=Coeliac ganglion, *I*=Superior mesenteric ganglion, *J*=Inferior mesenteric ganglion, *a*=Greater splanchnic nerve, *b*=Lesser splanchnic nerve, *c*=least splanchnic nerve.
C=Cervical cord, T=Thoracic cord, L=Lumbar cord, S=Sacral cord.

III. **Fore limb.** *Connectors*—T. 5–9. *Effectors*—First, second thoracic, middle and inferior cervical ganglia. Join brachial plexus and pass along the spinal nerves. Supply: (*a*) *Skin structures* (*vide* p. 5-284), (*b*) *Vessels* in skeletal muscles (dilators), etc.

IV. **Hind limb.** *Connectors*—T. 10–12 and L. 1–3. *Effectors*—from lumbar and sacral ganglia. Postganglionic sympathetic fibres join the lumbosacral plexus, pass along the spinal nerves and supply in the same way as the fore limb.

V. **Thoracic and abdominal wall.** *Connectors*—T. 1–12. *Effectors*—from the ganglia of the thoracic chain. Finally supply through the intercostal nerves.

VI. **Abdominal and pelvic viscera.** *Connectors* arise from T. 5 to L. 3, pass through the vertebral ganglia without relay, form the *splanchnic nerves* (preganglionic). There are greater, lesser and least splanchnic nerves. The *greater splanchnic nerve* arises from the fifth to ninth thoracic segments, the *lesser splanchnic nerve* from the tenth and eleventh thoracic segments, and the *least splanchnic nerve* from the twelfth thoracic segment. The greater splanchnic nerve ends in the upper part of the coeliac ganglion. The lesser splanchnic nerve ends in the lower part of the coeliac ganglion and the least splanchnic nerve joins the renal plexus and ends in small ganglia from where postganglionic sympathetic fibres arise and supply the kidney and ureter. The fibres arising from the first and second lumbar segments end in the inferior mesenteric ganglion (in animal) or in the hypogastric ganglion (in man). From here postganglionic sympathetic fibres arise and supply the viscera along the blood vessels.

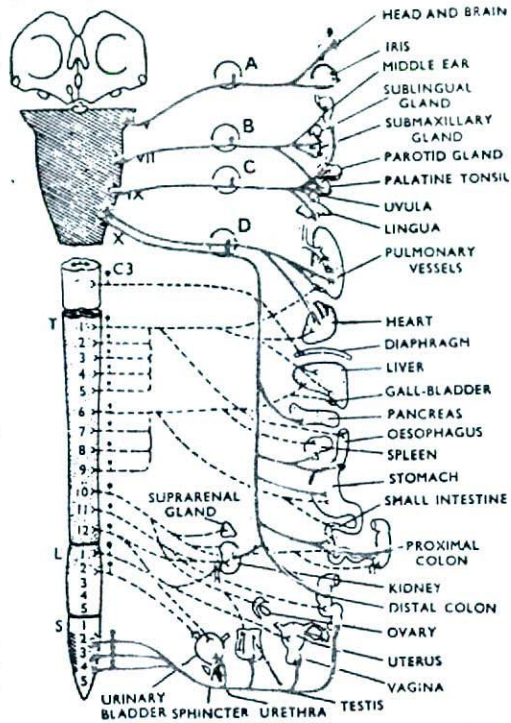


FIG. 5.268. Diagrammatic representation of projections of visceral afferent nerves showing spinal cord and brain stem centres. *Red lines* indicating afferent (parasympathetic) nerve fibres and *black lines* denoting afferent (sympathetic) nerve fibres. C.3=Third cervical outflow. A=Trigeminal ganglion (Geniculus gasseri), B=Geniculate ganglion (Geniculus geniculi), C=Petrosal ganglion, D=Nodose ganglion.

1. **Gastro-intestinal tract.** (*a*) *Oesophagus—no sympathetic supply.* (*b*) Whole of large and small intestine and stomach with all the sphincters in them, receive sympathetic supply (body of stomach—doubtful). **Action**—tone reduced, movements inhibited, sphincters constricted.

2. **Splanchnic vessels.** Richest vasoconstrictor supply. [Some vasodilators have also been demonstrated.]

3. **Urinary bladder.** Movements inhibited. Sphincters constricted (*vide* Chapter 4).
4. **Adrenal medulla.** Sympathetic supply only (secretomotor).
5. **Spleen and gall-bladder.** Contraction.
6. **Ureters.** *Both motor and inhibitory fibres from the sympathetic.* Parasympathetic absent.
7. **Kidney.** Constriction of glomerular arterioles, specially efferent (*vide* Ch. 4).
8. **Uterus, Fallopian tubes and vas deferens.** Both motor and inhibitory fibres from sympathetic
9 **Liver.** Glycogen mobilised.

PARASYMPATHETIC (CRANIOSACRAL) SYSTEM

Parasympathetic outflow takes place from the cranial and sacral regions. The connector cells of the cranial outflow lie in the cranial nerve nuclei (FIG. 5.269). The connector cells of the sacral region lie in

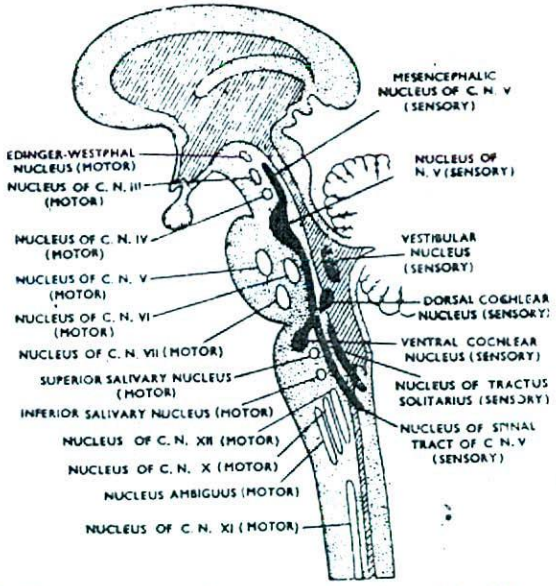


FIG. 5.269. Diagram represents the anatomical positions of the different cranial nerve nuclei.

the lateral horn cells. The presence of the peripheral ganglia is also a characteristic feature but unlike the sympathetic system the ganglia lie in or near the viscera except Meckel's ganglion and otic ganglion. Hence the parasympathetic system exerts a more localised action than the sympathetic system.

PARASYMPATHETIC OUTFLOW

I. **Cranial outflow.** Takes place through four cranial nerves—**oculomotor** (III), **facial** (VII), **glossopharyngeal** (IX), **vagus** (X). They are briefly described below.

1. **Oculomotor** (Third cranial nerve). *Connectors* arise from the most cranial part of oculomotor nucleus (Edinger-Westphal nucleus), relay in the ciliary ganglion, from where postganglionic **parasympathetic** fibres arise, pass in the short ciliary nerve and supply the ciliary muscles and sphincter pupillae. This nerve is also included within the midbrain outflow or tectal outflow.

2. **Facial nerve** (Seventh cranial nerve). *Connectors* arise from the dorsal nucleus (superior salivary nucleus) and pass out in two ways: (*a*) One group passes through *greater superficial petrosal nerve* to the *sphenopalatine ganglion* (Meckel's ganglion) from where postganglionic parasympathetic fibres arise and supply the (*i*) lacrimal glands, (*ii*) plain muscles, blood vessels and glands of palate and nasopharynx. (*b*) Another group passes in the chorda tympani, then joins the lingual nerve and at the floor of the mouth the chorda tympani fibres separate from the lingual nerve and end in the ganglia (sublingual ganglion and submaxillary ganglion) close to the submaxillary and sublingual glands (*vide* Volume I). Postganglionic parasympathetic fibres arise from these ganglia and supply secretory and vasodilator fibres to the glands. [Taste fibres from the anterior two-thirds of tongue also end in this nucleus forming a reflex arc for salivation. Hence, the name *superior salivary nucleus.*]

3. **Glossopharyngeal nerve** (Ninth cranial nerve). *Connectors* lie in the dorsal nucleus (inferior salivary nucleus), pass along the *tympanic nerve* and the *lesser superficial petrosal nerve* to the **otic ganglion.** Here, the postganglionic parasympathetic fibres arise, pass along the *auriculotemporal nerve* and supply secretory and vasodilator fibres to the parotid gland. [Taste fibres from the posterior one-third of tongue end in this nucleus and form a reflex arc for salivation. Hence, the name *inferior salivary nucleus.*]

4. **Vagus.** (Tenth cranial nerve). The vagus is the most important parasympathetic nerve, widely distributed and carries the parasympathetic fibres practically everywhere in the body except the limbs. *Connectors* arise from the small-celled part of the dorsal nucleus known as the *nucleus intercalatus* (Staderini's nucleus). Fibres pass out in the vagus trunk (preganglionic), end in ganglia—in or near the viscera, from where postganglionic parasympathetic fibres arise and supply the viscera as mentioned below:

(*a*) **Heart**—Postganglionic parasympathetic fibres arise from the ganglion cells near the sinoatrial and atrioventricular nodes. Supply inhibitory fibres to the junctional tissues and cardiac muscles (*vide* Volume I) and dilator fibres to coronary vessels.

(*b*) **Lungs**—constrictor fibres to the bronchial muscles.

(*c*) **Gastro-intestinal tract**—supply the tract *from the oesophagus up to caecum.* Postganglionic parasympathetic fibres arise from Auerbach's plexus and Meissner's plexus. Fibres from the former supply the muscle coats, stimulate intestinal movements and inhibit the sphincters. Fibres from the latter supply vasodilator fibres and secretomotor fibres to the gastro-intestinal glands and mucosa.

(*d*) **Pancreas**—supplies secretory fibres to the pancreatic alveoli as well as to the islets of Langerhans.

(*e*) **Gall-bladder**—action reverse of the sympathetic fibres.

(*f*) **Liver and Kidney**—no appreciable effect.

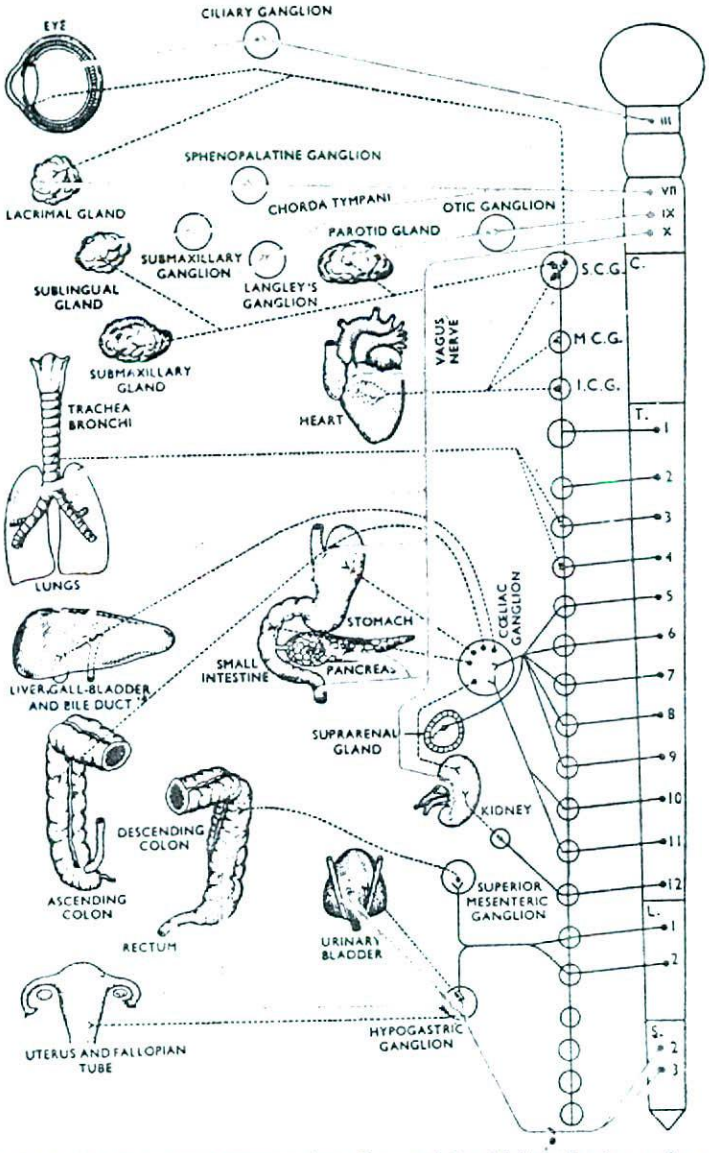


FIG. 5.270. Diagrammatic representation of some of the chief conduction pathways of the autonomic nervous system.

Black solid lines = preganglionic sympathetic fibres; *Black dotted lines* = postganglionic sympathetic fibres. *Red solid lines* = preganglionic parasympathetic fibres; *Red dotted lines* = postganglionic parasympathetic fibres. S.C.G. = superior cervical ganglion. M.C.G. = middle cervical ganglion. I.C.G. = inferior cervical ganglion. C. = cranial segments. T. = thoracic segments. L. = lumbar segments. S. = sacral segments.

II. **Sacral outflow.** Connectors from S. 2 and S. 4, pass out through corresponding anterior roots and unite to form a single nerve on each side called *nervi erigentes* (preganglionic). They relay in the hypogastric ganglia, from where postganglionic parasympathetic fibres arise and supply urinary bladder, prostate and *the whole of large intestine except caecum.* **Action:** (*i*) Movements stimulated and sphincters inhibited (reverse of the sympathetic). (*ii*) Also supplies dilator fibres to the blood vessels of external genitalia. This vasodilatation is an important factor for causing erection of penis (hence, the name *nervi erigentes*).

III. **Spinal parasympathetic.** Posterior spinal nerve roots contain certain fibres which on stimulation produce vasodilatation. These fibres are said to be parasympathetic as their action, unlike that of other vasodilator nerves, is not abolished by atropine. These fibres are also known as antidromic vasodilator fibres as their impulses pass out against the general afferent impulses of the posterior nerve roots and extend up to posterior root ganglion. Local stimulation by irritants applied to the skin produces vasodilatation through these fibres. This is known as axon reflex. The vasodilatation is produced due to liberation of acetylcholine at the nerve endings.

Higher autonomic centres. The activities of higher centres in the brain influence peripheral autonomic nervous system. The parts of the brain especially concerned have been described in the CNS and include some of the nuclei in the hypothalamus and certain areas of the cortex of the frontal lobe. The activities of the cerebral cortex in relation to the autonomic nervous system indicate a close relationship between mental states and visceral and somatic activities.

Functions of sympathetic and parasympathetic systems. In summary, the sympathetic and parasympathetic systems, by acting oppositely, take part in maintaining the body temperature mechanism in response to changes in external or internal environments. The **sympathetic system** directs to strengthen the subject's ability to adapt itself following a change in its internal environment, such as fall in heart rate, blood sugar, blood pressure, etc., and in external environment for securing foods and protection. Whereas the **parasympathetic system** is concerned with restoring and conserving energy. In most instances the parasympathetic system takes part in inhibiting or slowing down the different bodily processes.

Conclusion. Though the actions of the sympathetic and the parasympathetic system are antagonistic, i.e., if one system inhibits a function, the other activates it, but it is not always true. Because it depends upon the efficacy of transmitters released by either system and on the area of innervation. For example, the sympathetic stimulation markedly enhances peripheral vascular resistance, but it is not altered appreciably by the activity of parasympathetic system. In general, most of the vessels involved in the control of blood pressure are innervated only by the sympathetic nerve fibres and these fibres are continuously active. The parasympathetic nerve fibres which serve blood vessels normally are restricted to small areas of the body, and vasodilatation in these areas does not contribute appreciably to systemic blood pressure. So, to decrease blood pressure, it is more significant to paralyse the continuous sympathetic activity (tone) than to elicit the parasympathetic action. Further informations

on the function of the peripheral autonomic system have been discussed on the digestive system, the circulatory system and endocrinology.

Sympathetic and parasympathetic actions are summarised below:

The salient anatomical features of the sympathetic nervous system:

Preganglionic cell bodies in the CNS nuclei	*Postganglionic cell bodies in peripheral ganglia*	*Organs supplied*
Intermediolateral nucleus in cord segments C. 8–T. 2 (T. 3 sometimes)	Superior cervical ganglion and scattered along carotid plexus	Iris of eye
Intermediolateral nucleus in cord segments T. 1–T. 2	Superior and middle cervical sympathetic ganglia	Lacrimal gland
Intermediolateral nucleus in cord segments T. 1–T. 3 (T. 4 sometimes)	Superior and middle cervical sympathetic ganglia	Submandibular and sublingual glands
Intermediolateral nucleus in cord segments T. 1–T. 3 (T. 4 sometimes)	Superior and middle cervical sympathetic ganglia	Parotid gland
Intermediolateral nucleus in cord segments T. 1–T. 3	Superior, middle and inferior cervical sympathetic ganglia	Sweat glands of head and neck
Intermediolateral nucleus in cord segments T. 1–T. 5	Inferior cervical and thoracic (T. 1–T. 5) sympathetic ganglia	Lungs and bronchi
Intermediolateral nucleus in cord segments T. 1–T. 5 (T. 6, T. 7 sometimes)	Superior, middle and inferior cervical and thoracic (T. 1–T. 6) sympathetic ganglia	Heart
Intermediolateral nucleus in cord segments T. 1–T. 6	Thoracic sympathetic T. 4–T. 6 (T. 1–T. 6) ganglia	Oesophagus
Intermediolateral nucleus in cord segments T. 5–T. 11	Celiac and superior mesenteric ganglia	Stomach, small intestine, ascending and transverse colon
Intermediolateral nucleus in cord segments T. 12–L. 3	Lumbar and inferior mesenteric sympathetic ganglia	Descending colon and rectum
Intermediolateral nucleus in cord segments T. 10–L. 2	Lumbar, sacral and inferior mesenteric sympathetic ganglia	Sex organs
Intermediolateral nucleus in cord segments T. 12–L. 2	Lumbar and inferior mesenteric sympathetic ganglia	Urinary bladder
Intermediolateral nucleus in cord segments L. 1–L. 2	Lumbar and sacral sympathetic ganglia	Sweat glands and blood vessels of lower extremity

The salient anatomical features of the parasympathetic nervous system:

Preganglionic cell bodies in the CNS nuclei	*Postganglionic cell bodies in peripheral ganglia*	*Organs supplied*
Edinger-Westphal nucleus of midbrain (Cranial part of III nerve nucleus)	Ciliary ganglion	Sphincter pupillae Ciliary muscle
Superior salivary nucleus in pons varolii (Dorsal nucleus of C.N. VII)	Pterygopalatine ganglion	Lacrimal gland
Superior salivary nucleus in pons varolii (Dorsal nucleus of C.N. VII)	Submandibular ganglion	Submandibular and sublingual glands
Inferior salivary nucleus in medulla (Dorsal nucleus of C.N. IX)	Otic ganglion	Parotid gland
Dorsal motor nucleus of vagus (C.N. X)	Ganglia of pulmonary plexuses	Lungs and bronchi
Dorsal motor nucleus of vagus (C.N. X)	Intracardiac ganglia of atria	Heart
Dorsal motor nucleus of vagus (C.N. X)	Myenteric (Auerbach's) and submucous (Meissner's) plexuses	Oesophagus
Dorsal motor nucleus of vagus (C.N. X)	Myenteric (Auerbach's) and submucous (Meissner's) plexuses	Stomach, small intestine, ascending and transverse colon
Dorsal motor nucleus of vagus (C.N. X)	Submucous (Meissner's) plexus	Pancreas: endocrine and exocrine cells
Autonomic nucleus of intermediate gray column in cord segments S.2–S.4	Ganglia of haemorrhoidal myenteric and submucous plexuses	Descending colon and rectum
Autonomic nucleus of intermediate gray ramus in cord segments S.2–S.4 *Nervi erigentes*	Ganglia along branches of aorta and inferior iliac arteries (e.g., ovarian, uterine)	Sex organs
Autonomic nucleus of intermediate gray ramus in cord segments S.2–S.4 *Nervi erigentes*	Ganglia along vesical branches of inferior iliac artery	Urinary bladder

The effects of stimulation of autonomic adrenergic and cholinergic nerves are summarised below and many of these effects are discussed in more detail in other sections of the text:

Adrenergic impulses		*Cholinergic impulses*	*Effector organs*
Receptor type	*Responses*	*Responses*	
α	Contraction (mydriasis)		*Eye:* Iris radial muscle
		Contraction (miosis)	Iris circular muscle (sphincter pupillae)
β	Relaxation for far vision (slight effect)	Contraction, accommodation for near vision	Ciliary muscle
	Lid retraction		Lid smooth muscle
β	Increased heart rate (tachycardia)	Decreased heart rate (bradycardia), vagal arrest	*Heart:* S.-A. node
β	Increased contractility and conduction velocity	Decreased contractility and (usually) increased conduction velocity	Atria
	Increased conduction velocity	Decreased conduction velocity; A.-V. block	A.-V. node and conduction system
β	Increased contractility and conduction velocity; Increased irritability; extrasystoles		Ventricles
α β	Constriction Dilatation		*Blood vessels:* Coronary
α	Constriction		Skin and mucosa
α β	Constriction Dilatation	Dilatation	Skeletal muscle
α	Slight constriction		Cerebral
α	Constriction		Pulmonary
α β	Constriction Dilatation		Abdominal viscera
α	Constriction	Dilatation	Salivary glands
α	Constriction		Renal
β	Relaxation	Contraction	*Lung:* Bronchial muscle
		Stimulation of mucous secretion	Bronchial glands

Adrenergic impulses		*Cholinergic impulses*	*Effector organs*
Receptor type	*Responses*	*Responses*	
β	Usually decrease	Increase	*Stomach:* Motility and tone
α	Usually contraction	Usually relaxation	Sphincters
	Inhibition	Stimulation, especially enzymes	Secretion
α, β	Decrease	Increase	*Intestine:* Motility and tone
α	Usually contraction	Usually relaxation	Sphincters
		Stimulation	Secretion
	Relaxation	Contraction	*Gall-bladder and ducts*
β	Usually relaxation	Contraction	*Urinary bladder:* Detrusor
α	Contraction	Relaxation	Trigone and internal sphincter
	Usually increase		*Ureter:* Motility and tone
α, β	Variable (responses influenced by stage of menstrual cycle, amount of circulating oestrogen and progesterone, etc., and by pregnancy)	Variable	*Uterus*
	Ejaculation in male	Vasodilatation and erection (penis, clitoris)	*Sex organs*
α	Contraction		*Skin:* Arrectores pili
α	Slight, localised secretion (on palms and in other locations adrenergic sweating)	Generalised secretion	Sweat glands
α	Contraction		*Spleen capsule*
		Secretion of epinephrine and norepinephrine	*Adrenal medulla*
β	Glycogenolysis		*Liver*

Adrenergic impulses		*Cholinergic impulses*	*Effector organs*
Receptor type	*Responses*	*Responses*	
		Secretion	*Pancreas:* Exocrine glands
α	Inhibition of insulin secretion	Insulin secretion	Islets
β	Insulin secretion		
		Secretion	*Salivary glands:* Parotid
α	Thick, viscous secretion	Profuse, watery secretion	Submaxillary
		Secretion	*Lacrimal glands*
		Secretion	*Nasopharyngeal glands*
		Stimulation	*Autonomic ganglion cells*
β	Release of FFA (lipolysis)		*Adipose tissue*
β	Renin secretion		*Juxtaglomerular cells*

HUMORAL MECHANISM OF TRANSMISSION OF NERVE IMPULSES BY AUTONOMIC NERVES

A nerve impulse is not transmitted directly—either through the nerve endings or through the synapses. It passes through an intermediate chemical agent. It has been established that certain chemical substances are actually liberated at these regions which help the transmission of nerve impulses. They are as follows: (1) **norepinephrine,** and (2) **acetylcholine.**

Norepinephrine

The chemical transmitters at most of the postganglionic sympathetic nerve endings, are closely similar to epinephrine. Though the postganglionic adrenergic fibres secrete both epinephrine and norepinephrine, the relative proportions of their secretion vary from nerve to nerve. But the major mediator in postganglionic sympathetic fibres is norepinephrine which probably corresponds to **Cannon's sympathin.**

All evidences indicate that excepting the nerve fibres to the sweat glands (cholinergic), norepinephrine is liberated at all the postganglionic sympathetic nerve endings and thus initiates the peripheral sympathetic action. *It should be noted that the sympathetic system has a companion gland—the adrenal medulla, which also secretes the epinephrine and norepinephrine* (*vide* Chapter 4).

The granules in the sympathetic nerve endings have been proved to contain norepinephrine by fluorescence staining. Norepinephrine and its methyl derivative, epinephrine are secreted by adrenal medulla. Norepinephrine and epinephrine are present in most visceral organs but it is

the norepinephrine which is correlated with the sympathetic nerve fibres to the organ. Drugs which block the effects of epinephrine, but not of norepinephrine, have no effect on the response of the sympathetically innervated organs. After removal of the adrenal gland, the epinephrine content of the blood is lowered whereas the norepinephrine content is changed relatively little.

Through histologic fluorescent techniques and electron microscopic observations, it has been learned that the sympathetic nerve consists of a cell body, a long axon and highly-branched nerve terminals. The nerve terminals possess swellings or varicosities (Fig. 5.271). These varicosities lie in close proximity to effector cells. One sympathetic neurone can innervate about 25,000 effector cells. Within the swelling or varicosity the neurotransmitter, norepinephrine, is stored in vesicles of about 500 Å in diameter. Richardson (1964) has described three types of granular vesicles. *Type I* having diameter of about 840 A is present numerously in the presynaptic terminals of autonomic ganglia. *Type II* is found in axons associated with ganglia and possesses diameter of about 470 Å. *Type III* vesicle is found in the nerve endings of smooth muscle and has a very dense central core. Dahlstrom (1965) has described that granular vesicles are synthesised in the soma of the neurone. This type of structural organisation is present both in the central nervous system and also in the autonomic nervous system.

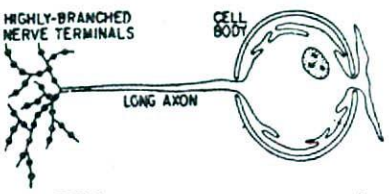


Fig. 5.271. Diagrammatic representation of sympathetic synaptic neurone with terminal varicosities.

Synthesis, storage, uptake, release and metabolism of norepinephrine (NE) have already been described (*vide* Catecholamines in Ghapter 4).

Norepinephrine after being formed in the sympathetic neurones is

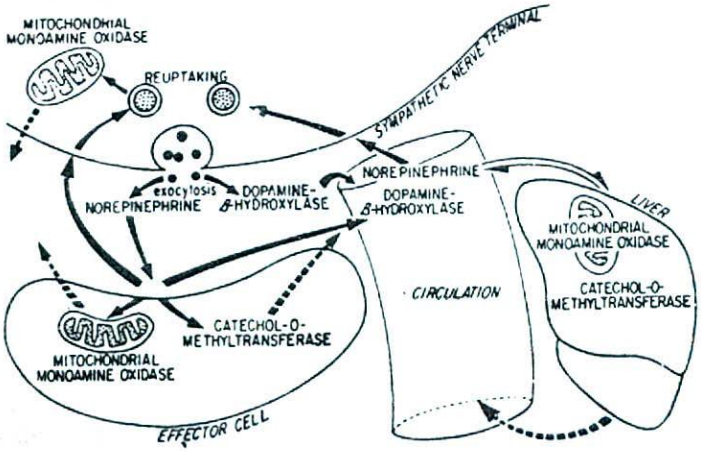


Fig. 5.272. Schematic representation of fate of NE (norepinephrine) at a varicosity of the sympathetic nerve terminal.

stored in dense core vesicles along with the norepinephrine-producing enzyme *dopamine-β-hydroxylase*. When this nerve is depolarised, the NE is released from the vesicle by the process of exocytosis in which Ca^{++} is required. Along with NE, the enzyme dopamine-β-hydroxylase is also released. It has been suggested that NE, after being liberated may be taken up by the cell membrane and subsequently reincorporated into storage granules until it is destroyed by the *monoamine oxidase* (MAO) within the terminals. So long the NE remains within the storage granules it is safe from destruction though the MAO is present in the mitochondria of the same neurone. Actions of NE at the effector cells are terminated by reuptake into the neurone, removal by circulation and subsequent metabolism in the liver or by metabolism in the effector cell by *catechol-o-methyl transferase* (COMT) and mitochondrial *monoamine oxidase* (MAO) (Fig. 5.272). MAO inactivates excessive amounts of NE that may leak out of the storage vesicles. Thus NE is inactivated by MAO and is *intracellular*, and also by COMT and is *extracellular*. MAO appears to play a role in regulating the intraneuronal storage level of NE and dopamine in catecholamine-containing neurones in the CNS and autonomic nervous system. Norepinephrine is formed continuously within the neurone and amino-oxidase serves to keep down the concentration of this when the non-granular portion of it becomes too high.

Drugs that act on the release of NE from nerve terminals

Certain sympathomimetic amines have got some effects in releasing the NE from the nerve terminals. These amines (*amphetamine*, *metaraminol* and *synephrine*) are structurally similar to NE and enter the storage vesicles and displace NE which is then discharged into the synaptic cleft in a physiologically active form causing rise of blood pressure (Fig. 5.273 I & II).

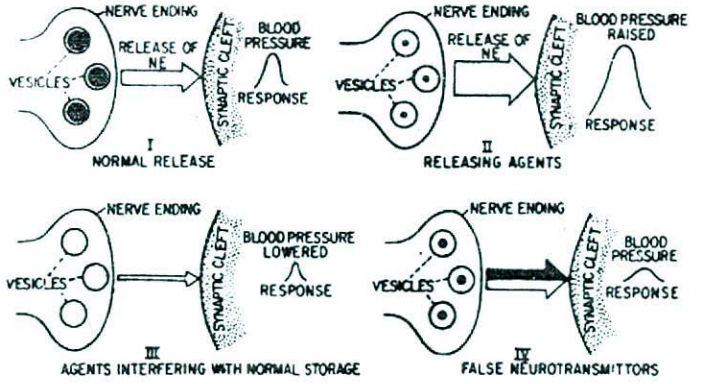


Fig. 5.273. Action of drugs on the release of NE from sympathetic nerve terminals (*after Axelrod & Other*).

These amines are destroyed only by MAO For this reason, if monoamine oxidase inhibitor is administered along with these amines then symptoms of hypertension are encountered due to excessive activity of NE.

Reserpine and *guanethidine* prevent the retention of NE within the storage granules and thus the NE is depleted from the granular vesicles.

It is thought that these drugs act by destroying binding sites within the intraneuronal storage particles of adrenergic neurones. These events cause complete depletion of catecholamine content from the neurones of sympathetic nervous system and the CNS. Due to administration of reserpine, free catecholamine is not released from the cell. Before being discharged from the cell, the catecholamine is oxidised intraneuronally by MAO as because non-granular (extravesicular) NE is capable of rapid oxidation by MAO. So NE after being released from the vesicle by reserpine is rapidly oxidised by MAO into its metabolic products that have got very little hypertensive properties (Fig. 5.273III). Thus the reserpine and guanethidine cause fall of blood pressure by preventing the retention of NE in its storage vesicles and ultimately deplete the neurotransmitter from the tissue.

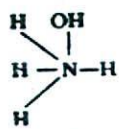
Another groups of compound, like α-methyl norepinephrine (formed from α-methyl-dopa), metaraminol and octopamine and also compounds related in structure to norepinephrine when administered, are stored within the storage vesicles of the sympathetic neurones and released along with the NE. Because of their lower pressor activity, these compounds dilute the actions of the normal transmitter NE on the effector cells. Metaraminol and other similar drugs when administered, cause initial rise of pressure by direct stimulation of adrenergic receptor along with release of NE from the storage granules in an active form. On prolonged therapy of such compounds, NE is displaced from the storage granules and the compound itself acts like false neurotransmitter (Fig. 5.273 IV).

Sympathin

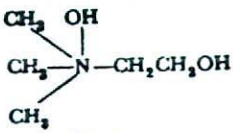
To explain this differential sympathetic action Cannon and Rosenblueth postulated the 'sympathin' theory. They hold that two types of sympathins are produced at the nerve endings: (*a*) sympathin E (excitation), and (*b*) sympathin I (inhibition). A third mediator compound M travels in blood. The local effect is due to a combination ME or MI. The former produces excitation and the latter inhibition. But recent views are that there is liberation of epinephrine and norepinephrine at the nerve endings.

Acetylcholine

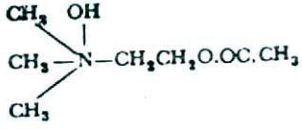
Chemistry and synthesis. Acetylcholine is the *acetyl ester of* strong quaternary base, *choline*. It is synthesised in the body by the interaction of acetyl CoA and choline in presence of enzyme *choline acetylase* (Fig. 5.275). The acetyl CoA is formed from acetic acid and CoA.SH in presence of ATP and of enzyme *acetyl thiokinase*. The choline is the derivative of *ammonium hydroxide* whose hydrogen atoms, attached to the nitrogen, are replaced by three methyl groups and one hydroxy ethyl group.



Ammonium hydroxide



Choline



Acetylcholine

Choline is synthesised by progressive (successive) methylation of ethanol amine (the decarboxylated products of serine, *vide* Volume I). The

methyl group of active methionine (adenosyl methionine) is the sole donor of methyl groups to the choline though the methionine gets its methyl group from one carbon unit through tetrahydrofolate.

In the body acetylcholine is formed in the following regions:

1. At all parasympathetic nerves and nerve endings. Constantly produced in small amounts (tonic action). Rate increases on stimulation of parasympathetic nerves.
2. At those sympathetic nerve endings (cholinergic) which supply the sweat glands and arrectores pili.
3. At all the synapses—in the autonomic and somatic nervous system. Acetylcholine, produced at the synapses, plays an important role in the passage of nerve impulses.
4. At the endings of antidromic vasodilator fibres in the posterior root. [*Vide* page 5-290.]

Nerve fibres liberating acetylcholine are known as **cholinergic fibres** which include somatic motor fibres, autonomic preganglionic fibres, sympathetic and parasympathetic and parasympathetic post-ganglionic fibres (FIG. 5.263).

Neurophysiological functions of ACh as chemical transmitter at synapses. Mechanisms of release and also how does it act have been studied by microelectrode technique. Due to cable properties of axon, the impulse is transmitted quickly to the axon terminal. Depolarisation of axon terminal (knob) is accompanied by a local movement of ions, including Ca^{++} ions, the entry of which is essential for transmitter (ACh) release process. After a certain delay 'quanta' of ACh, probably 5000–50,000 molecules each is released on the presynaptic membrane. The acetylcholine thus diffuses across the synaptic cleft and combines with the specific receptor molecules of postsynaptic membrane. This combination, the *acetylcholine receptor complex* leads to change of permeability to smaller ions causing depolarisation of the postsynaptic cell and thereby leading to muscle contraction, glandular secretion or initiation of further nerve impulses. ACh is afterwards hydrolysed quickly by the *acetylcholine esterase* (AChE) present in the synaptic membrane.

Nature of action. Acetylcholine acts in the following ways: (1) Direct peripheral action—independent of nerve, e.g., dilatation of certain blood vessels, contraction of certain organs (intestine and uterus), etc. (2) Parasympathomimetic action on all tissues supplied by cholinergic fibres. *Seat of action*—just distal to the nerve endings. (3) Nicotine-like action on the ganglia. Acetylcholine stimulates all autonomic ganglia like small doses of

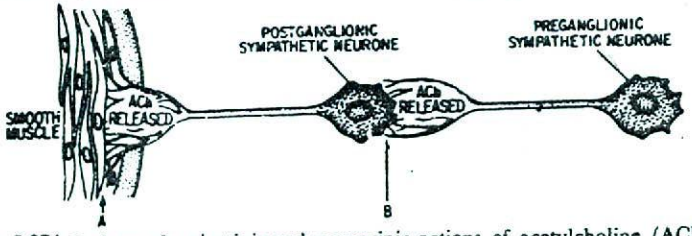


FIG. 5.274. It shows the nicotinic and muscarinic actions of acetylcholine (ACh). At A, ACh, like muscarine, stimulates smooth muscles and glands, i.e., muscarine action of ACh. At B, ACh, like nicotine, stimulates conduction in autonomic ganglia, but in large amounts depresses, i.e., nicotinic action of ACh.

nicotine.(4) **Muscarine action.** Muscarine stimulates the smooth muscle innervated by the cholinergic fibres. Like muscarine, acetylcholine also stimulates the smooth muscle acting on the effector organs (FIG. 5.274).

Responses of effector organ, to cholinergic and adrenergic impulses have been presented in pp. 5-293 – 295.

Action of acetylcholine

I. **Transmission of nerve impulses.** Important actions of acetylcholine are the transmission of nerve impulses in neuromuscular junctions, synaptic junctions and in autonomic ganglia.

II. **Circulation**

1. Small intravenous doses (1×10^{-5} mgm or even less) in cat lowers blood pressure. **Cause**—Direct vasodilator action on certain blood vessels, e.g., of ear. *Abolished by atropine.*

2. With larger doses (0·01–0·1 mgm)—blood pressure falls considerably. **Cause**—Chiefly vagal effect on heart: Occurs even after bilateral vagotomy, but abolished by atropine (shows that it acts just outside the vagal endings).

3. Very large doses (5 mgm) may raise blood pressure even after atropine. **Cause**—Stimulation of sympathetic ganglia leading to vasoconstriction. [Parasympathetic is already paralysed with atropine.]

III. **Heart.** In lower doses (0·00007 μ gm) it stimulates the heart but higher doses inhibits the heart through hyperpolarisation of the cell membrane.

IV. **Uterus.** Stimulates contraction by direct action on the muscle coat.

V. **Intestine.** Stimulates contraction by direct action on the muscle coat.

VI. **Skeletal muscles.** Stimulate the contraction of the skeletal muscle.

VII. **Central nervous system.** Studies of pharmacological action of acetylcholine on the spinal cord show that the effects differ according to the condition of the spinal cord. When given intravenously in the decerebrate cats, it stimulates the anterior horn cells. But when given in the cat under chloralose anaesthesia, it inhibits the anterior horn cells. Anyway, it shows that acetylcholine can both stimulate or inhibit the neurones under different conditions.

VIII. **Other tissues and organs.** Same as parasympathetic stimulation.

IX. **Emotion and behaviour.** The acetylcholine is not only important in regulating the somatic and visceral motor activities but also emotion, behaviour and other complex functions of the brain.

Functions of acetylcholine

1. Being produced at the motor-end plate it helps in the development of end plate potential (EPP).

2. Exerts parasympathomimetic action on all tissues supplied by cholinergic autonomic fibres.

3. Exerts direct peripheral action on certain tissues and organs, viz., uterus.

4. Plays an important role in the transmission of nerve impulses through the somatic and autonomic synapses. It is the mediator of impulses at all autonomic ganglia, all parasympathetic postganglionic terminals and preganglionic terminals, sympathetic preganglionic terminals, sympathetic postganglionic terminals at sweat glands and at motor nerve endings in the skeletal muscle.

Fate of acetylcholine

Cholinesterase. Acetylcholine, formed in the synaptic vesicle or in the cholinergic nerve endings, is rapidly destroyed by **specific** or **true acetylcholine esterase** into acetic acid and choline (FIG. 5.275). The specific acetylcholine esterase is present in high concentration in cholinergic nerve terminals. The specific cholinesterase has the capacity of hydrolysing acetylcholine only. There is another cholinesterase present in the cell membrane, placenta, red blood cells and also in plasma. It can hydrolyse acetylcholine as well as other choline esters and for this reason

this type of esterase is known as **non-specific** or **pseudocholinesterase.** Thus the enzyme, present in body fluids and tissues, quickens the hydrolysis of acetylcholine and thereby its destruction. It is due to this enzyme that acetylcholine fails to produce any prolonged cumulative action. Eserine,

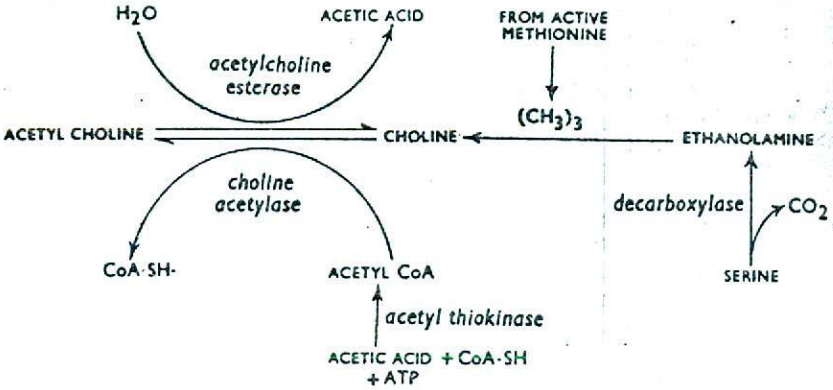


FIG. 5.275. Schematic representation of formation and breakdown of acetylcholine.

prostigmine, diisopropylfluorophosphate (DFP) and tetraethylpyrophosphate (TEPP) inhibit the action of cholinesterase, thus prolonging and strengthening the action of acetylcholine. Hence, these drugs are collectively known as anticholinesterases. They produce the same effects as parasympathetic stimulation

CONTROL OF THE AUTONOMIC NERVOUS SYSTEM

The autonomic nervous system is controlled in the following ways:

I. **Nervous control**

(*a*) **Hypothalamus** (*vide* pages 5-305 – 306).

(*b*) **Cerebral cortex:**

In spite of the fact that decorticate animals maintain almost normal autonomic functions, following facts suggest that cerebrum probably exerts a controlling effect on the autonomic nervous system. (*i*) Stimulation of area 13 (on the under surface of the frontal lobe) causes cardiac acceleration, etc. (*ii*) From areas 6 and 13 of the cerebral cortex afferent impulses are projected to the hypothalamus. Stimulation of same areas of the cerebral cortex increases blood pressure, while stimulation of other foci has the opposite effect. Both the sympathetic and parasympathetic systems are represented in the cerebral cortex and stimulation of certain cortical areas may result the continued effect of both the two systems.

Lacrimation can be observed by stimulation of cortical eyefields; also salivation may appear by stimulating the motor representation of the face and tongue. Cardiovascular reactions can be obtained by electrical stimulation of motor areas 4 and 6.

Disturbances of sweat secretion may result from stimulation of area 6, while ablation of this area abolishes some sweating reflexes.

(*c*) **Centres in the brain stem and medulla.** The medullary centres for the autonomic reflex control of circulation, heart, respiration, vomiting, coughing, sneezing, etc., are called the **vital centres.** The

afferent fibres connecting to these centres originate from the visceral receptors located at the particular sites like carotid and aortic bodies, stretch receptors, etc. The motor or effector pathways originating from the medulla pass through either sympathetic or parasympathetic pathways. The details of these reflexes such as: (*a*) vasomotor centre (*vide* Volume I), (*b*) cardiac centre (*vide* Volume I), (*c*) pupil-dilating centre—situated in the medulla, controls the pupil-dilating sympathetic fibres, etc., are discussed in the respective chapters.

II. **Hormonal control.** Epinephrine, norepinephrine and also acetylcholine control the autonomic nervous system through the activation of the certain hypothalamic nuclei.

HYPOTHALAMUS

Hypothalamus (*Basal part of diencephalon*). It is the highest centre for the autonomic nervous system (FIG. 5.276).

The *diencephalon* comprises the *thalamus* and the **hypothalamus.** The hypothalamus is derived from the basal plate (*ala ventralis*) of the diencephalon as ventral part of it and forms a complexity of nuclei and fibres which are connected with higher and deeper levels of the central nervous system and the hypophysis. So the hypothalamus is the higher projection centre of visceral afferent impulses.

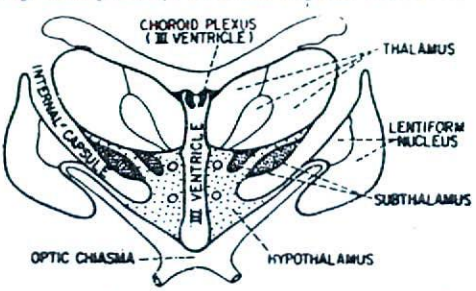


FIG. 5.276. Schematic representation of frontal section through the diencephalon and related structures.

The hypothalamus has got close connection with the hypophysis and is concerned with a complex neurohormonal regulatory apparatus. The posterior lobe of the hypophysis develops from the ventral part of the infundibulum, whereas the anterior lobe of the hypophysis originates from the so-called Rathke's pouch.

The hypothalamus forms the lower part of the lateral and the anterior wall of the third ventricle and is situated at the interpeduncular space somewhat anterior to and below the thalamus. The hypothalamic sulcus separates it from the thalamus. Antero-laterally the hypothalamic sulcus continues in the paraterminal gyrus and the paraolfactory part of the frontal lobe. Anteriorly and medially it is centinuous in the optic chiasma and the supraoptic commissures on the floor of the third ventricle. It is seen from the base that the cerebral peduncles and optic fasciculus circumscribe the hypothalamus.

It consists of the following nuclear masses (FIG. 5.277).

I. **Anterior group.** In relation with optic chiasma: (*a*) *medial preoptic nucleus*, (*b*) *lateral preoptic nucleus*, (*c*) *supraoptic nucleus*, (*d*) *suprachiasmatic nucleus*, (*e*) *paraventricular nucleus*, (*f*) *anterior hypothalamic nucleus.*

II. **Middle group.** Situated in close relation with infundibulum and tuber cinerum (nucleus tuber): (*a*) *ventromedial hypothalamic nucleus*, (*b*) *dorsomedial hypothalamic nucleus*, (*c*) *lateral hypothalamic nucleus*, (*d*) *posterior hypothalamic nucleus*, (*e*) *arcuate nucleus.*

III. **Posterior group.** In close relation to the wall of the third ventricle and mammillary body. (*a*) *nucleus intercalatus* (*Staderini's nucleus*), (*b*) *premammillary nucleus*, (*c*) *supramammillary nucleus*, (*d*) *medial mammillary nucleus*, (*e*) *lateral mammillary nucleus*.

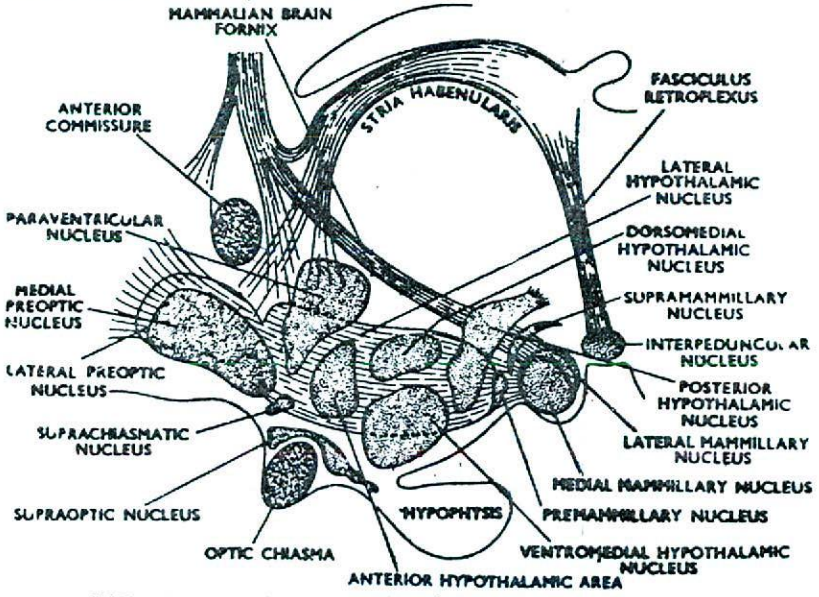


FIG. 5.277. Diagrammatic representation of relative positions of different hypothalamic nuclei (sagittal section) (*after La Grass Clark*).

Connections of hypothalamus (FIG. 5.278)

Hypothalamic nuclei receive a number of projections from different parts of the brain.

I. Afferent

1. **Corticomammillary fibres.** Area 6a and cingulate gyrus (areas 23, 24) project on the mammillary body, and also the hippocampus to the mammillary nuclei through the fornix.

2. **Fibres from medial thalamic nuclei.** From the dorsomedial thalamic nucleus and also from the midline nucleus to the hypothalamus through the thalamohypothalamic fibres

3. From the mesencephalic reticular formation to hypothalamus through the reticulohypothalamic fibres

4. **Olfactohypothalamic fibres.** From the olfactory bulb and the anterior perforated substance to the hypothalamic nuclei through the medial forebrain bundle.

5. From the globus pallidus to the hypothalamus (*pallidohypothalamic tract*) *via* the medial forebrain bundle and the ansa lenticularis.

6. From precentral motor area 6 and prefrontal areas of the cerebral cortex to the supraoptic and paraventricular nuclei through the corticohypothalamic fibres. Area 6 is also projected bilaterally on the ventromedial nucleus of *pars tuberalis*. Areas 8 and 10 activate the supraoptic nucleus whereas areas 10, 46 and 47 activate the paraventricular nucleus.

7. **Orbital lobe projections.** Area 13, the posterior part of the orbital cortex projects partly on the ventromedial hypothalamic nucleus and also projects on the supraoptic and paraventricular nuclei.

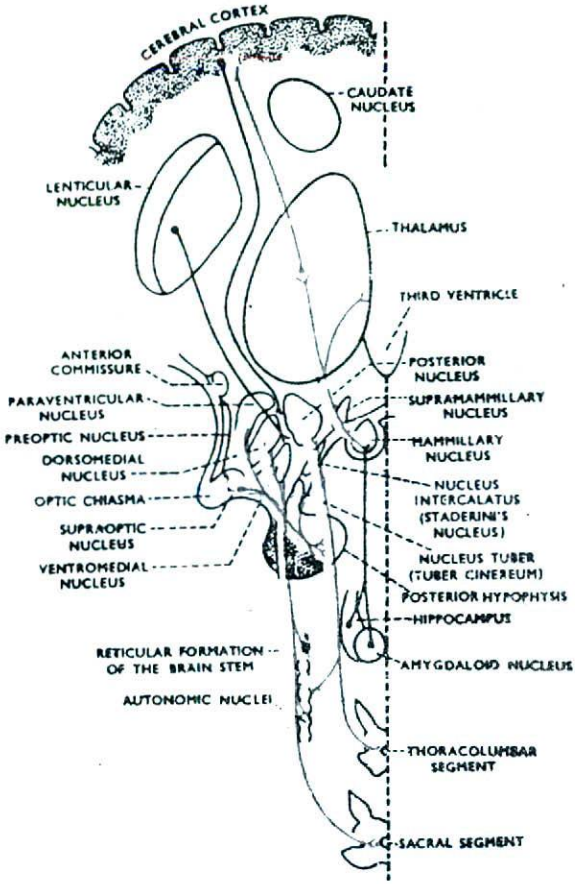


FIG. 5.278. Diagrammatic representation of some connections of hypothalamus. *Red* = efferent; *Black* = afferent.

II. Efferent

The hypothalamus sends, in turn, a number of projections to different areas.

1. Mammillothalamic tract—from the medial mammillary nucleus to anterior nucleus of thalamus.

2. To the dorsomedial thalamic nucleus and thence to the areas 11, 12, 10, 9, 8, 45, 46, 47 (FIGS. 5.227 & 5.228) of the cerebral cortex. [Periventricular projection.]

Efferent fibres of hypothalamus are projected mainly to the anteroventral group of the thalamus and thence it is projected to the areas 23 and 24.

3. Hypophysis—Hypothalamico-hypophyseal tract—from the supraoptic, paraventricular and tuberal nuclei to the posterior pituitary. Majority of the fibres end in the pituicytes of the pars nervosa. Some fibres also end in the pars intermedia. This connection is made up of a number of very thin unmyelinated fibres which by anastomosis end around capillary vessels of neurohypophysis.

4. From the lateral hypothalamic nucleus to the reticular formation of the tegmentum and autonomic nuclei in the brain stem and lateral horn cells of the spinal cord. Fibres controlling parasympathetic system originate from the **middle hypothalamic nuclei.** Those for the sympathetic system arise from **posterior hypothalamic nuclei.**

Free interconnections also exist between various hypothalamic nuclei.

FUNCTIONS OF HYPOTHALAMUS

The functions of the hypothalamus have been studied both by stimulating electrically certain parts of the hypothalamic nuclei or by ablating or making selective lesion of the hypothalamus. The major functions are given below. In general, the posterior hypothalamus contains predominantly sympathetic representation, while the middle and anterior nuclei contain parasympathetic representation. Some of the functions related with those groups of nuclei may appear clear cut, while majority of the functions include complex behavioural and emotional reactions.

1. **Controls sympathetic nervous system.** The posterior nuclei of the hypothalamus are particularly concerned with this function. Stimulation of these nuclei raises blood pressure, increases epinephrine secretion, causes tachycardia, vasoconstriction, dilatation of pupils, inhibition of intestinal movements, etc. Karplus and Kreidl were the first to observe widespread manifestation of sympathetic excitation after stimulation of the wall of the third ventricle. In 1957 Hess with the help of Stereotaxic instrument was able to elucidate the functional organisation of the hypothalamus, specially in relation to behaviour. Stimulation of the anterior part of the hypothalamus in animals causes *rage phenomenon*, e.g., erection

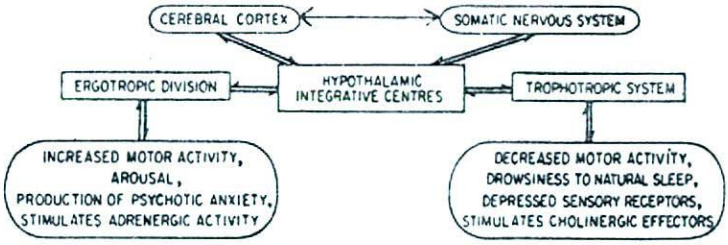


FIG. 5.279. Hypothalamic integrative mechanism indicating a hypothetical balance between ergotropic and trophotropic systems. The degree of behavioural response depends upon the amount and/or frequency of stimulation of that system.

of the hairs, dilatation of the pupils, growling, sweating, etc. These effects were called by Hess as *ergotropic effects* and are mediated through ergotropic or sympathetic system (FIG. 5.279). The ergotropic system helps to meet the emergency. The drug chlorpromazine depresses the ergotropic system. Lesions of posterior nuclei produce lethargy, hypothermia and

Horner's syndrome. Experimental decortication in animals produces signs of sympathetic hyperactivity. This is a release phenomenon—hypothalamus being released from cortical control.

2. **Controls parasympathetic nervous system.** The middle hypothalamic nuclei are mainly concerned with this function. Stimulation of these nuclei causes parasympathetic hyperactivity, viz., slowing of the heart rate, contraction of pupils, etc. These effects were called by Hess as *trophotropic effects* and are mediated through trophotropic or parasympathetic system (FIG. 5.279). The trophotropic system is related to protective mechanism. The drugs reserpine and serotonin stimulate the trophotropic system. Irritative lesions may cause haemorrhagic erosions in the mucous membrane of stomach, duodenum, oesophagus, etc.

3. **Takes part in regulation of body temperature.** Stimulation of the posterior nuclei of the hypothalamus produces vasoconstriction, shivering, struggling and also raises blood pressure. Lesion of the posterior part of the hypothalamus abolishes shivering, vasoconstriction, etc., and the animal cannot respond to cold and cannot protect itself from the increased environmental temperature. The animals may become poikilothermic. Transection of the brain stem below the level of the hypothalamus affects the regulation of body temperature at any environmental conditions. This section also makes the animal poikilothermic. Stimulation of the anterior nuclei of the hypothalamus produces vasodilatation, sweating, panting, etc. Lesion of the anterior part of the hypothalamus abolishes vasodilatation, sweating, panting, etc., when the animal is exposed to high temperature. These experiments prove that the heat-regulating centre is situated in the hypothalamus.

It is clear from the above observations that there are two separate temperature-regulating centres—one mostly occupying anteriorly and the other posteriorly in the hypothalamus. The anteriorly placed nuclei mostly regulate temperature during overheating by sweating, panting, vasodilatation, etc., and the posteriorly placed hypothalamic nuclei regulate body temperature during extreme cold by shivering, piloerection, vasoconstriction, epinephrine secretion, etc. Thus the hypothalamus plays as *thermostat* which maintains normal body temperature by the co-ordinated activities of the above two different systems. It is claimed that for the functions of thermostat mechanisms, two receptive mechanisms are playing. One such is the peripheral cutaneous thermoreceptors which constantly feed impulses to the hypothalamic thermoregulatory centre with the change of environmental temperature. Other such is the centrally located thermodetectors which respond to changes in intracranial temperature.

4. **Important reflex centre for emotional expression.** Goltz, Britton and Cannon have shown that removal of the cerebral hemispheres and a large part of the thalamus in dogs and cats produced the following phenomena, immediately after recovery from the anaesthesia, i.e., erection of the hairs, dilatation of pupils, lashing of the tail, growling, sweating, etc., —(*Sham rage*). Hess has shown that by stimulation of the anterior part of the hypothalamus in animals also causes outbursts of mental excitation (*Rage phenomenon*). Bard has shown that ablation of the *neocortex* (isocortex) makes the animal *placid*. Ablations of neocortex and limbic structures make the animal *wild*. The neocortex diminishes the manifestations of rage reactions. Limbic structures exert an inhibitory effect over the

hypothalamic centre causing rage phenomenon (*vide* also page 5-272). The rage reactions that occur in the decorticate animal disappear in lesion of the hypothalamus. Ingram, Barris and Ranson in 1936 observed that lesions in the supramammillary area of the hypothalamus in cats produce somnolence, loss of voluntary movement, undue plasticity of the muscles, aversion to food, etc. From these effects it has been suggested that the hypothalamus is probably related to wakefulness due to its connection with thalamic and reticular arousal systems (*arousal response*).

It is also concerned with the **personality of a subject.** Lesions cause changes of personality and psychic disturbances.

5. **Related to hunger, feeding, obesity and thirst.** In 1953 Delgado and Anand have shown that the extreme lateral part of the

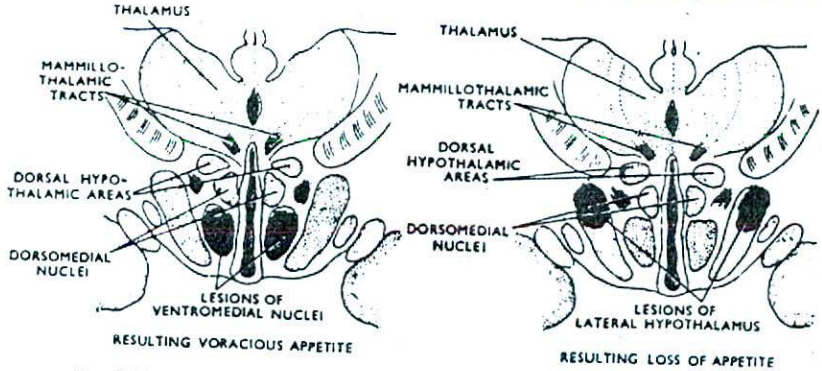


FIG. 5.280. Diagrammatic representation of effects of hypothalamic lesions on feeding (*after Ganong*).

ventromedial nucleus of the hypothalamus is responsible for hyperphagia —*feeding centre.* Stimulation of this area causes increased food intake. Bilateral lesion of this area, in cats, produces complete cessation of food intake. Medial part of the ventromedial nucleus has got controlling effect on the *feeding centre.* Bilateral lesion of the medial part of the ventromedial nucleus causes hyperphagia and the animals become *obese.* Further, lesion of the lateral part of the ventromedial nucleus in the same animal produced complete cessation of food intake by the animal (FIG. 5.280). Medial part of the ventromedial nucleus when adequately supplied with glucose

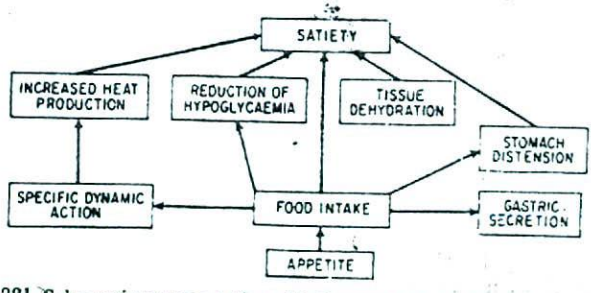


FIG. 5.281. Schematic representation of influences of factors on changes from appetite to satiety where eating itself being of the factors.

has inhibitory effect on the lateral part of the ventromedial nucleus (i.e., on the *feeding centre*), but if the medial part of the ventromedial nucleus is inadequately supplied with glucose it activates *feeding centre*. All these effects have been studied by Larsson on 1954 by the use of radio-active glucose. It has been suggested that the medial part of the ventromedial nucleus acts as a *satiety centre* (Fig. 5.281). A *drinking centre* has been localised in the hypothalamus in rats. Injection of hypertonic saline near the paraventricular nucleus in rats caused excessive drinking of water (*polydipsia*).

6. **Sexual functions.** Brookhart and Dey in 1941 observed that lesion on the ventral part of the hypothalamus produces changes in sexual behaviour in male guinea-pigs towards female ones. In decorticate female cat there was no change in the oestrous cycle so long as the hypothalamus remained intact. Bard in 1940 has shown that lesion of the caudal part of the hypothalamus causes inhibition of the oestrous cycle in animals (Fig. 5.282).

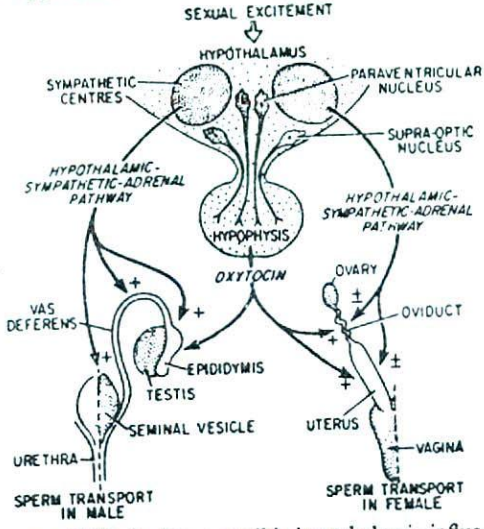


Fig. 5.282. It shows possible hypothalamic influences on sperm transport in the male and female rabbits in which *plus* and *minus* signs indicate excitatory and inhibitory effects on contractile activity respectively (*after Cross*).

7. **Concerned with sleep.** Stimulation of the posterior hypothalamus by weak current induces a state resembling prolonged sleep. Ingram, Barris and Ranson observed that lesions in the supramammillary area in animals produces somnolence with loss of voluntary movement and peculiar muscular tone. Hypothalamus is also related to wakefulness probably through its connection with the reticular arousal system. Lesions of the posterior hypothalamus cause *coma*.

With the help of these functions hypothalamus maintains the physical and chemical constancy (*homeostasis of Cannon*) of the internal environment (*milieu intérieur* of Claude Bernard) which is essential for the normal life processes of the organism. *Just as somatic nervous system adjusts the body against* **external environment,** *so the autonomic nervous system combats all forces that try to alter the* **internal environment** *and thus, helps to keep the latter constant.*

8. **Posterior pituitary functions.** (*a*) Regulation of Water-balance. It has been described earlier (*vide* Volume I) that hypothalamus plays an important role in the maintenance of water-balance of the body through the liberation of antidiuretic hormone (vasopressin) from the posterior pituitary. Hypothalamic nuclei, supraoptic and paraventricular, are connected with the posterior pituitary through unmyelinated hypothalamico-hypophyseal tract (Fig. 5.283). Posterior pituitary hormones are

formed in the hypothalamic nuclei and transported to the posterior pituitary through the hypothalamico-hypophyseal tract. The antidiuretic hormone promotes the reabsorption of water through the renal tubules and thus limits the water loss from the body. If the supraoptic nucleus, paraventricular nucleus or median eminence, are damaged then produce diabetes insipidus—the condition which enhances excretion of water from the body.

Antidiuretic hormone secretion is modified under different conditions such as water deprivation, plasma hyperosmolarity, changes in blood volume and pressure, negative pressure respiration, positive pressure respiration, haemorrhage and changes in blood volume. Beside these, **osmoreceptors** are present in the hypothalamus within the following areas such as medial and lateral preoptic areas, anterior hypothalamic area, paraventricular and supraoptic nuclei, anterior hypothalamic area, ventromedial nuclei and dorsal and lateral hypothalamic areas. The pars nervosa is not the site for the osmoreceptors. The receptors are stimulated by the increase of blood NaCl concentration and antidiuretic hormone (*vide* Volume 1) is liberated from the posterior pituitary producing **anuresis.**

(*b*) OXYTOCIN SECRETION. Like ADH, the oxytocin is also secreted from the hypothalamus and thence transported to the neurohypophysis. It has been described earlier that oxytocin is important in parturition (Chapter-4) and milk ejection (Chapter 4). Stimulation of supraoptic hypophyseal tract causes liberation of oxytocin.

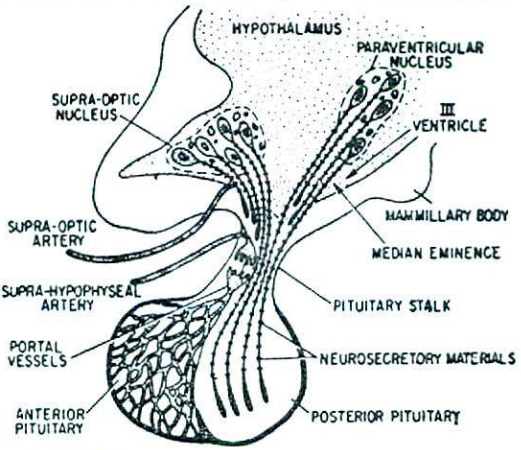


FIG. 5.283. Diagrammatic representation of the functional relationship between the hypothalamus and hypophysis in mammals.

9. **Anterior pituitary functions.** REGULATION OF ADENOHYPOPHYSEAL FUNCTIONS (FIG. 5.283). Hypothalamus being the guardian of the pituitary, regulates the secretory functions of the anterior pituitary. It has been reported with substantial evidences that hypothalamic axons which end in the capillary loops in the median eminence, liberate multiple hypothalamic hormones or factors.

Recently Schally *et al* (1973) reported the presence of nine hypothalamic regulatory hormones that control the secretion of the pituitary hormones (FIG. 5.284). These hormones are:

(*i*) Corticotrophin releasing hormone or factor (CRH or CRF).
(*ii*) Thyrotrophin releasing hormone or factor (TRH or TRF).
(*iii*) Luteinising hormone releasing hormone or factor (LH-RH or LH-RF).

(*iv*) Follicle-stimulating hormone releasing hormone or factor (FSH-RH or FSH-RF).

(*v*) Growth hormone releasing hormone or factor (GH-RH or GH-RF).

(*vi*) Growth hormone release-inhibiting hormone or factor (GH-RIH or GIF).

(*vii*) Prolactin release-inhibiting hormone or factor (PR-IH or PIF).

(*viii*) Prolactin releasing hormone or factor (PRH or PRF).

(*ix*) Melanocyte-stimulating hormone release-inhibiting hormone or factor (MR-IH or MIF).

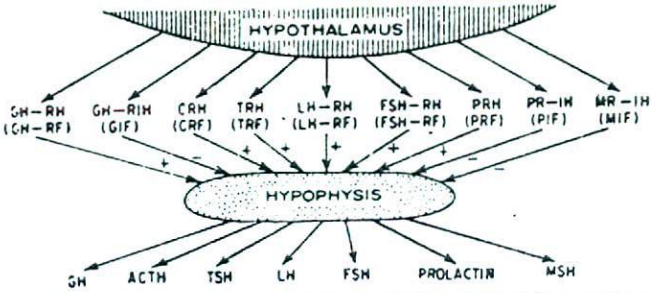


FIG. 5.284. Schematic representation of hypothalamic releasing factors that control the secretion of different hormones of the hypophysis.

Presence of releasing hormones or factors like GH-RF, TRF, CRF, LH-RF, FSH-RF and inhibitory factor, the PIF have already been described (*vide* Adenohypophysis, Ejection of milk, etc., in Chapter 4).

The presence of prolactin releasing hormone or factor (PRH or PRF), growth hormone releasing-inhibitory hormone or factor (GH-RIH or GIF) and melanocyte-stimulating hormone releasing-inhibitory hormone or factor (MSHR-IH or MIF) have recently been described by Schally *et al* (1973). Nicoll *et al* (1970) and Schally *et al* (1973) have reported that hypothalamic extracts of rats, pigs and birds contain PRH or PRF in addition to PR-IH or PIF. Though TRH or TRF has got some prolactin releasing activity, yet it cannot be considered as physiological PRH or PRF as because hypothalamic extract, completely devoid of TRH still possesses the prolactin releasing property. The existence of GHR-IH or GIF has been suggested by Krulich *et al* (1968). But its existence has not been confirmed. Etkin (1962) first reported the existence of inhibitory factors of MSH in the hypothalamic extract. This has been substantiated further by Kastin *et al* (1965-66). The chemical nature of such inhibitory factor has also been determined.

There is evidence of the presence of MSH releasing hormone or factor, but its existence in hypothalamic tissue has not been substantiated.

Hypothalamic lesions have been found to interfere with hypophyseal functions. If the median eminence is damaged so that the vascular link in between the hypothalamus and pituitary is cut off then certain hypophyseal secretory function is permanently lost with the exception of LTH, MSH and SRF which are secreted in large amounts.

10. **Relation with gastric acid secretion.** It is a well-known fact

that hypothalamus is involved in the mechanism of gastric juice secretion. Overactivity of hypothalamus due to emotional upset, through liberation of insulin leads to injury of the stomach for excess gastric acid secretion. Porter and others have demonstrated the increase secretion of gastric acid following stimulation of rostral part of the hypothalamus. Furthermore, the patients under prolonged emotional stress are prone to the occurrence of gastric ulcer. The peptic ulcer is generally known as **psychosomatic disorder** or more correctly the **hypothalamo-somatic disorder.** It is claimed that this hypothalamo-somatic disorder is involved through two efferent pathways: (*i*) one is the vagus—because the vagotomy ameliorates the condition, (*ii*) humoral—acting through the adenohypophysis and the adrenal cortex. Insulin-induced excess gastric juice secretion appears to act *via* hypothalamus through the above two pathways.

11. **Cardiovascular regulation.** Hypothalamus being the higher centres of the autonomic nervous system regulates the heart rate, blood pressure, circulation and also takes part in vasomotor adjustment under any condition like increased blood pressure, decreased blood pressure, haemorrhage, hypoxia, etc. Beside these, adaptive cardiovascular adjustment under fear, anger and rage takes place through the hypothalamo-sympathetico-adrenal activity. Hypothalamic lesion often causes oedema in the lungs and also haemorrhage.

12. **Relation with stress through neurohormonal mediation.** In any condition of stress, hypothalamus plays a prime role in combating the syndrome through the activation of adrenal-pituitary axis. The stress factors may act directly on the hypothalamus and indirectly on the

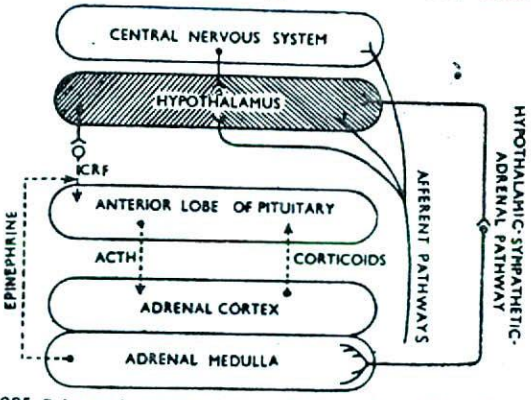


FIG. 5.285. Schematic representation of interactions of hypothalamus, anterior pituitary and adrenal medulla.

adrenal cortex. The stress syndrome is thus combated through the mediation of hypothalamic-sympathetic-adrenal system and the hypophyseal-cortico-suprarenal system (FIG. 5.285).

NEUROSECRETION

Modern concept of neurosecretion. The modern concept of neurosecretion has come from the studies on the vertebrate hypothalamo-neurohypophyseal complex (HNC). From such studies, the neurosecretory cells have been described as a neurone with the morphological and

functional characteristics of nerve and endocrine cells. According to such concepts neurosecretory cells may receive input from other neurones and may be capable of propagating action potential down the action. Their axon do not form any synapse with other neurones or effector organs but the axon of neurosecretory cells ends at vascular spaces into which they release the neurosecretory materials or neurosecretion. According to the definition *neurosecretions are neurohormones, polypeptide in nature and are sequestered within membrane bound vesicles of diameter greater than* 1000 Å. Electron microscopic studies have revealed the presence of electron dense granules—the neurosecretory granules (NSG) having diameter 1000 A to 3000 Å. Neurosecretory material is the aggregates of neurosecretory granules. The cell body of the neurone synthesises and packages the neurohormones within NSG. The neurosecretory granules are aggregated into neurosecretory materials and transported through the axoplasm along the axon to the region of the nerve terminals and are discharged into the blood stream.

Nature of neurosecretory cells

(*a*) **Neuronal characteristics.** The neurosecretory cells are nothing but specialised neurones having the ability to synthesise and to secrete hormones. Like ordinary neurones there are axon and dendrites extensively developed endoplasmic reticulum, Golgi complex, neurofibrils, etc. But these cells do not have synaptic connections with other neurones.

(*b*) **Glandular characteristics.** The neurosecretory cell is an endocrine cell directly involved with the control of endocrine activity. The glandular characteristic of the cell is due to direct contact of the cell apex with the basement membrane through which secretory materials are discharged out. Like other endocrine cells (pancreas, pituitary), these cells are capable of synthesising protein hormones and thus are well equipped with the organelles taking active part in synthesising the protein for the hormones. These organelles—the endoplasmic reticulum and Golgi bodies are well developed. Thus the neurosecretory cells differ from the ordinary neurosecretory cells by the presence of electron dense materials with Golgi membranes.

Significance of neurosecretory cells. The fundamental significance of the neurosecretory cells is the *final common path* upon which a vast array of neural information is channelled to endocrine organs and by which neural inputs are translated into endocrine function. Bodily systems such as somatic and visceral system are under the dual control of the nervous system and endocrine system. The endocrine system is the effector arms of the nervous system and the functional status of the endocrine system is under the control of the nervous system.

Nature, synthesis, transport and release of neurosecretory materials. Neurosecretory materials are protein in nature. It is in some molecules glycoproteins and also sometimes lipoprotein. The chemistry of most neurosecretory materials is not known. The chemistry of neural lobe hormones has been characterised successfully. It is within the family of cyclic cystine system containing octapeptides. Crustacean neurosecretory hormones are also protein in nature.

Protein of the neurosecretory materials is synthesised as usual in the endoplasmic reticulum of the soma and transported to the Golgi bodies

where these proteins are packaged into electron dense vesicular granules (Fig. 5.286). These vesicular granules are aggregated to form the neurosecretory materials. The possibility of synthesis of neurosecretory materials in the axon or axon terminal cannot be excluded. Electron microscopic studies (Knowles, 1964) indicate such possibility. Thus the entire neurosecretory cell can be considered as a synthetic unit.

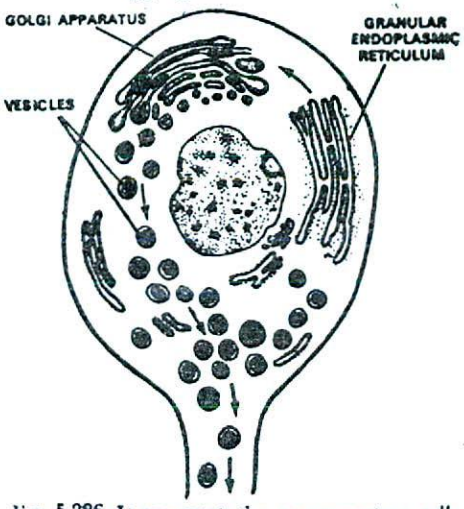


Fig. 5.286. It represents the neurosecretory cells and perikaryal synthesis of neurosecretory materials (diagrammatic).

Neurosecretory materials, after being formed, are transported from the site of its production to the site of its discharge through the **axoplasmic flow** along the axon. The presence of carrier protein in the transport of the NSM has been reported. Such carrier protein in case of neural lobe hormones is neurophysin having molecular weight of about 20,000. There are at least two neurophysins in neural lobe hormones but whether there is separate neurophysin for each neural lobe hormone is not yet known.

Recent studies reveal that neurosecretory materials are released from the bulbous enlargement present all throughout the axon and axon terminals. These also suggest that a series of bulbous enlargement along single axon could serve as loci for release of neurohormones from the neurohypophysis. Recent electrophysiological studies reveal that nerve impulses travelling down the supra-opticohypophyseal tract trigger the release of hormones. The hypothalamic neurosecretory neurones are influenced by impulses carrying from different parts of the CNS, some of which are cholinergic or adrenergic or of an inhibitory in nature. It is known that the neurosecretory materials just before release are broken down into minute microvesicles which then fuse with the neuronal membrane and is ultimately discharged into the extracellular space.

Inadequacies of classical definition of neurosecretion. The definition of neurosecretion as described above is not so broad and thus unsatisfactory when it is considered with the other neurosecretory cells distributed in the body or present in different species. Median eminences of certain tetrapod contain neurosecretory fibres, which end on capillaries but the axon terminals display some catecholamine-containing vesicles. In some insects, fishes, amphibians and in mammals, the neurosecretory cells possess direct contact with the endocrine cells. Knowles and Vollrath (1966) have described from their observations in eel that the endocrine glands, the pars intermedia and adenohypophysis, are innervated by at least two different types of neurosecretory fibres—type A and type B (Fig. 5.287A). Type A fibres generally contain peptide hormones in

spherical electron-dense vesicles of diameter greater than 1000 Å. Type B fibres contain **irregular** vesicles of monoamines and have diameter less than 1000 Å. Both types of fibres discharge their secretory materials within the perivascular (extravascular) space (FIG. 5.287B) from which the materials diffuse to the target cells. Different types of neurosecretory fibres and their nature of termination in the target organs have been presented in FIG. 5.287.

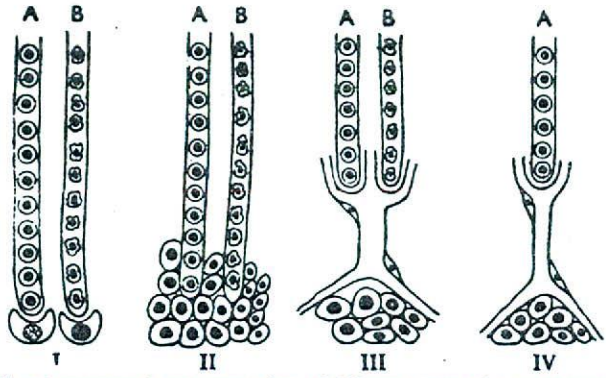


FIG. 5.287. Diagrammatic representation of different types of neurosecretory fibres and their modes of communication with target cell (*after Sachs*, 1970)
I = direct contact, II = perivascular space, III = portal vessel, and IV = systemic blood vessel.

From the above discussion it is clear that the classical definition of neurosecretion as described earlier is not perfect. Welsh (1961) and De Robertis (1964) have pointed out that all neurones are practically engaged in secretory activity and by which active substances are synthesised and released. With this it is apparent that there should not be any distinct boundary in between the true neurones and neurosecretory cells. Knowles and Bern (1966) have proposed a functional definition of neurosecretory cells which is as follows:

Neurosecretory cells are those which are directly or indirectly engaged in endocrine control and may form all or part of what may be regarded as a traditional endocrine organ. It is this activity which should be considered as the fundamental criterion for designating a neurone as neurosecretory. But the above definition is so generic that it covers the major portion of the nervous system including many sensory, internuncial and cortical neurones that are directly or indirectly engaged in endocrine control. Thus search for a unitary concept of the definition of neurosecretion is of absolute importance.

Distribution and functions of neurosecretory cells. The principal vertebrate neurosecretory systems are found in hypothalamus which contains specific groups of neurosecretory cells. Among the neurosecretory neurones in the CNS, the hypothalamo-neurohypophyseal complex (HNC) of higher vertebrates is the most ideal neurosecretory system that truly fulfil the classical feature of a neurosecretory cells. These neurosecretory cells secrete about 7 octapeptides (*vide* Ch. 4).

The other groups of neurosecretory cells that are present in the hypothalamus are the hypothalamo-adenohypophyseal system (HAS).

This system controls the functions of the adenohypophysis. Their relationship to adenohypophyseal function has been studied extensively in lower mammals. This region of the hypothalamus (medial basal hypothalamus) has been termed as the **hypophysiotropic area.** These hypophysiotropic neurones in higher vertebrates do not innervate the hypophyseal cells directly but these neuronal axons end in the median eminence and discharge their neurosecretory materials into the network of capillary tufts. These capillary tufts drain these NSM into the hypothalamico-hypophyseal portal system. About eight hypothalamic neurosecretory substances have been isolated and characterised clearly to have distinct separate functions (*vide* page 5-309).

Another type of hypothalamic neurosecretory cell is present and this cell is concerned with the control of the secretion of melanocyte-stimulating hormones (MSH) of the pars intermedia.

There are two other neurosecretory systems which are (*i*) caudal neurosecretory system of fishes, and (*ii*) neurosecretory fibres that control the pineal gland. In most fishes the caudal portion of the spinal cord contains neurosecretory cells. The axons of neurosecretory cells end in a neurolemmal area which is known **urophysis**. These neurosecretory cells are concerned with osmoregulation.

The function of pinealocyte is under the control of neurosecretory fibres present within the pineal gland.

There are also other neurosecretory fibres distributed elsewhere in the brain of vertebrates.

CRANIAL NERVES

There are 12 pairs of cranial nerves arising directly from the brain (FIG. 5.5 in page 5-3). These cranial nerves are: I cranial nerves—*olfactory*, II cranial nerves—*optic*, III cranial nerves—*oculomotor*, IV cranial nerves—*trochlear*, V cranial nerves—*trigeminal*, VI cranial nerves—*abducens*, VII cranial nerves—*facial*, VIII cranial nerves—*vestibulocochlear* or *acoustic*, IX cranial nerves—*glossopharyngeal*, X cranial nerves—*vagus*, XI cranial nerves—*spinal accessory*, and XII cranial nerves are *hypoglossal* (FIG. 5.288).

Among the cranial nerves described above, the olfactory, optic and vestibulocochlear are **sensory** in function, the hypoglossal and spinal accessory are **motor** in function, and the oculomotor, trochlear, trigeminal, abducens, facial, glossopharyngeal and vagus are **motor** and **sensory** in functions. For anatomical positions of different cranial nerve nuclei *vide* FIG. 5.269.

For convenience, the origin, distribution and functions have been presented in the following tabular form.

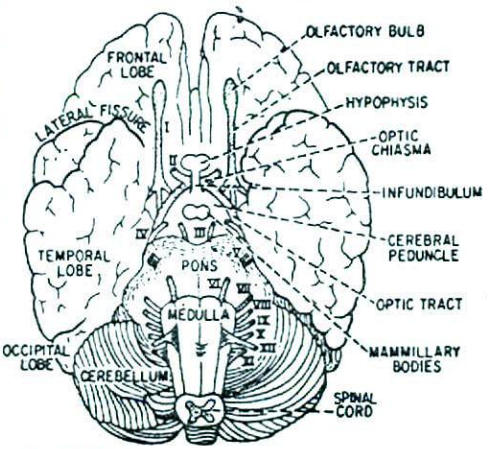


FIG. 5.288. Diagrammatic representation of the undersurface of the brain. The numerals show the cranial nerves.

Analysis of cranial nerves

Common name (Modality)	Components or Types of fibres	Origin	Organs innervated	Central connection	Functions
I—Olfactory	(*a*) Special somatic sensory (afferent).	(*a*) Nasal mucous membrane.	(*a*) Olfactory epithelial cells.	(*a*) (*i*) Olfactory bulb. (*ii*) Parts of rhinencephalon.	(*a*) Sense of smell.
II—Optic	(*a*) Special somatic sensory (afferent).	(*a*) Ganglionic layer of retina.	(*a*) Retina.	(*a*) (*i*) Lateral geniculate body. (*ii*) Visuosensory cortex (area 17). (*iii*) Superior colliculus. (*iv*) Pretectal nucleus.	(*a*) Visual sensation.
III—Oculomotor	(*a*) Somatic motor (efferent). (*b*) General somatic sensory (afferent). (*c*) General visceral motor (efferent).	(*a*) III cranial nerve nucleus. (*b*) Mesencephalic nucleus of trigeminal nerve and bipolar cells along oculomotor nerve. (*c*) Edinger-Westphal nucleus.	(*a*) Medial rectus, inferior rectus and inferior oblique muscles. (*b*) Ciliary muscles. (*c*) (*i*) Sphincter pupillae. (*ii*) Levator muscle of upper eyelid. (*iii*) Superior rectus muscle of the eyeball.	(*a*) Frontal eyefields (areas 4, 6, 8) and areas 17, 18, 19. (*b*) (*i*) Thalamus, (*ii*) Cerebellum. (*iii*) Postcentral gyrus (areas 3, 1, 2). (*c*) Pretectal nucleus and cerebral cortex.	(*a*) Eyeball movements. (*b*) Proprioception of muscles of eyeball. (*c*) (*i*) Contraction of pupil. (*ii*) Accommodation.
IV—Trochlear	(*a*) General somatic sensory (afferent). (*b*) Somatic motor (efferent).	(*a*) Mesencephalic nucleus of trigeminal nerve and bipolar cells along trochlear nerve. (*b*) IV cranial nerve nucleus.	(*a*) Superior oblique muscle of eyeball.	(*a*) (*i*) Thalamus. (*ii*) Cerebellum. (*iii*) Postcentral gyrus (areas 3, 1, 2). (*b*) Middle frontal gyrus (area 6).	(*a*) Proprioception of superior oblique muscle of eyeball. (*b*) Movements of eyeball.
V—Trigeminal (Trifacial)	(*a*) Special visceral (branchial) motor (efferent).	(*a*) Motor nucleus of V cranial nerve.	(*a*) Pinna of the ear, lower part of the face, teeth and gums of the mandible.	(*a*) Precentral gyrus (area 4).	(*a*) Movement of mandible.

Common name (Modality)	Components or Types of fibres	Origin	Organs innervated	Central connection	Functions
V—Trigeminal (Trifacial)	(*b*) General somatic sensory (afferent).	(*b*) Trigeminal ganglion.	(*b*) Cornea, ciliary body and iris, lacrimal gland, conjunctiva, part of mucous membrane of nasal cavity, skin of eyelid, eyebrow, forehead and nose.	(*b*) (*i*) Thalamus. (*ii*) Postcentral gyrus (areas 3, 1, 2). (*iii*) Nucleus of spinal tract.	(*b*) Painful and thermal sensibility of skin, of face and scalp, of mucous membrane, of nose and mouth.
	(*c*) Do.	(*c*) Trigeminal ganglion.	(*c*) Dura mater, forehead, lower eyelid, lateral angle of orbit, upper lip, gums, teeth of upper jaw, mucous membrane and skin of cheek and of nose.	(*c*) (*i*) Thalamus. (*ii*) Principal sensory nucleus of V cranial nerve. (*iii*) Postcentral gyrus (areas, 3, 1, 2).	(*c*) Tactile and pressure sensibility of skin, of face and scalp, of mucous membrane, of nose and mouth.
	(*d*) Do	(*d*) Mesencephalic nucleus of V cranial nerve.	(*d*) Muscles of mastication, mucous membrane of the anterior part of tongue with the lingual nerve.	(*d*) (*i*) Postcentral gyrus (areas 3, 1, 2). (*ii*) Thalamus. (*iii*) Cerebellum.	(*d*) Proprioception of muscles of mastication.
VI—Abducens	(*a*) General somatic sensory (afferent).	(*a*) Mesencephalic nucleus of trigeminal nerve. Small nucleus beneath floor of IV ventricle. Bipolar cells along abducens nerve.	(*a*) Lateral rectus. (Fibres from III nucleus communicate with VI nucleus to co-ordinate activity of lateral and medial recti of two sides.)	(*a*) (*i*) Cerebellum. (*ii*) Postcentral gyrus (areas 3, 1, 2). (*iii*) Thalamus.	(*a*) Proprioception of lateral rectus. (Co-ordination is effected by fibres in medial longitudinal fasciculus.)
	(*b*) Somatic motor (efferent).	(*b*) VI cranial nerve nucleus.	(*b*) Lateral rectus muscle of eye.	(*b*) Middle frontal gyrus (area 6).	(*b*) Lateral movement of the eyeball.
VII—Facial	(*a*) General somatic sensory (afferent).	(*a*) Geniculate ganglion on the facial nerve.	(*a*) External ear and middle ear and mastoid region.	(*a*) Postcentral gyrus (areas 3, 1, 2). Thalamus. Cerebellum.	(*a*) Proprioceptive (Facial muscles, etc.).
	(*b*) Special visceral (branchial) motor (efferent).	(*b*) VII cranial nerve nucleus.	(*b*) Muscles of face, neck, pinna and part of scalp.	(*b*) Precentral gyrus (area 4).	(*b*) Facial expression and elevation of hyoid bone.

Common name (Modality)	Components or Types of fibres	Origin	Organs innervated	Central connection	Functions
VII—Facial—(*contd.*)	(*c*) Special visceral sensory (afferent).	(*c*) Geniculate ganglion on the facial nerve.	(*c*) Taste buds of anterior two-thirds of tongue.	(*c*) (*i*) Postcentral gyrus (areas 3, 1, 2). (*ii*) Thalamus. (*iii*) Nucleus of tractus solitarius.	(*c*) Taste.
	(*d*) General visceral motor (efferent)—secretomotor (parasympathetic).	(*d*) Superior salivary nucleus. Lacrimatory nucleus.	(*d*) Sublingual and submaxillary salivary glands. Lacrimal glands.	(*d*) (*i*) Nucleus of spinal tract. (*ii*) Nucleus of V cranial nerve.	(*d*) Secretion of saliva. Lacrimation.
VIII—Vestibulocochlear					
(*a*) Cochlear	(*a*) Specific somatic sensory (afferent).	(*a*) Spiral ganglion of cochlea.	(*a*) Organ of Corti	(*a*) (*i*) Auditory cortex (areas 22, 41, 42). (*ii*) Cochlear nuclei. (*iii*) Inferior colliculus. (*iv*) Medial geniculate body.	(*a*) Hearing.
(*b*) Vestibular	(*b*) Special somatic sensory (afferent).	(*b*) Vestibular ganglion of internal auditory meatus.	(*b*) Semicircular canals. Utricle. Saccule.	(*b*) (*i*) Cerebellum. (*ii*) Flocculonodular lobe. (*iii*) Vestibular nucleus.	(*b*) Maintenance of equilibrium.
IX—Glossopharyngeal	(*a*) General visceral sensory (afferent).	(*a*) Inferior ganglion.	(*a*) Mucous membrane of pharynx and posterior third of tongue.	(*a*) ?	(*a*) Sensation for taste.
	(*b*) Special visceral sensory (afferent).	(*b*) Inferior ganglion.	(*b*) Taste buds of posterior third of tongue.	(*b*) (*i*) Thalamus. (*ii*) Nucleus of tractus solitarius. (*ii*) Postcentral gyrus (areas 3, 1, 2).	(*b*) Taste.
	(*c*) General somatic sensory (afferent).	(*c*) Superior ganglion.	(*c*) Stylopharyngeal muscles. Muscle of palatine tonsil and of adjacent part of soft palate. Carotid body, Carotid sinus.	(*c*) (*i*) Cerebellum. (*ii*) Postcentral gyrus (areas 3, 1, 2). (*iii*) Thalamus.	(*c*) Proprioception.
	(*d*) Special visceral (branchial) motor.	(*d*) Nucleus ambiguus.	(*d*) Muscles of larynx.	(*d*) Precentral gyrus (area 4).	(*d*) Elevation of larynx in deglutition.
	(*e*) General visceral motor (efferent).	(*e*) Inferior salivary nucleus.	(*e*) Secretory fibres to the parotid gland.	(*e*) ?	(*e*) Secretion of saliva.

Common name (Modality)	Components or Types of fibres	Origin	Organs innervated	Central connection	Functions
Vagus and Cranial root of accessory	(*a*) Special visceral sensory (afferent).	(*a*) Inferior ganglion (Nodose ganglion).	(*a*) Mucosa of epiglottis.	(*a*) (*i*) Postcentral gyrus (areas 3, 1, 2). (*ii*) Thalamus. (*iii*) Nucleus of tractus solitarius.	(*a*) Taste.
	(*b*) General visceral sensory (afferent).	(*b*) Inferior ganglion (Nodose ganglion).	(*b*) Mucous membrane of larynx, trachea, lungs, oesophagus, stomach, intestine, heart, gall-bladder and aortic body.	(*b*) (*i*) Nucleus of tractus solitarius. (*ii*) Frontal area.	(*b*) Sensation.
	(*c*) Special visceral (branchial) motor (efferent).	(*c*) Nucleus ambiguus in the medulla.	(*c*) Muscles of pharynx, larynx, trachea, oesophagus, stomach, small intestine, ascending colon, inhibitory fibres to heart, secretory fibres to gastric and pancreatic glands, trachea, spleen, kidneys, liver, pancreas.	(*c*) Precentral gyrus (area 4).	(*c*) Swallowing. Phonation. Intestinal or gastric movement. Visceral reflexes for heart and lung.
	(*d*) General visceral motor (efferent).	(*d*) Dorsal nucleus of X cranial nerve.	(*d*) Mucous membrane of stomach and small intestine.	(*d*) Posterior orbital gyrus (area 13).	(*d*) Movements.
	(*e*) General somatic sensory (afferent).	(*e*) Superior ganglion (Jugular ganglion).	(*e*) Central cutaneous part of auricle and external acoustic meatus.	(*e*) (*i*) Thalamus. (*ii*) Postcentral gyrus. (*iii*) Cerebellum (*iv*) Nucleus of spinal tract of V.	(*e*) Cutaneous sensibility.
Spinal accessory	(*a*) Special visceral motor (efferent).	(*a*) Lateral part of anterior gray column of spinal cord (C. 1–C. 5).	(*a*) Muscles of neck and shoulder.	(*a*) Precentral gyrus (area 4).	(*a*) Movements of head and shoulder.
XII—Hypoglossal	(*a*) Somatic motor (efferent).	(*a*) Hypoglossal nucleus of XII cranial nerve.	(*a*) Muscles of tongue.	(*a*) Precentral gyrus (area 4).	(*a*) Movement of tongue.

Morphological relationships of cranial nerves. The cranial nerves with their phylogenetic history and with their individual components (*vide* pp. 5-316-19) can be classified as follows:

Group I includes the III, IV, VI and XII cranial nerves and arises from the cells of somatic efferent column. These nerves are distributed to the musculature derived from the cranial myotomes. These all correspond to ventral nerve roots of the spinal nerves, and except the IV cranial nerve, they emerge from the brain stem, in line with them.

Group II includes the V, VII, IX, X and XI cranial nerves and innervates the derivatives of the branchial arches. This group differs from the spinal nerves in possessing motor roots which are distributed to the musculature derived from the neural crest and the lateral mesodermic plates of the branchial region. The V, X and XI cranial nerves are compound and have been formed by the fusion of two or more dorsal nerves. In the process cutaneous branches, originally connected with the VII, IX and X cranial nerves, have been taken over by the V, so that these all in man bear but little resemblance to their homologues in the lower vertebrates and still less to dorsal nerve roots of the spinal nerves.

Due to the complexity of their components, each nerve may possess more than one nucleus of origin and more than one nucleus of termination.

In spite of certain difficulties, the homologies of the nerves in Group I and Group II are commonly accepted, but the allocation of the I, II and VIII cranial nerves is still uncertain. On account of the mode of development with the exception of similar function of other cranial nerves the II cranial nerve is usually regarded as a special somatic afferent. The cells of the retina, from which its fibres are derived, really constitute an outlying part of the brain, although they are derivatives of the forerunners of the neural crest cells.

The I cranial (olfactory) and the VIII cranial (vestibulocochlear or acoustic) nerves may be grouped together or separately, or the vestibulocochlear nerves may be regarded as being homologous with a dorsal nerve. Both nerves arise, at least partly, from the ectodermal cells outside the area of the neural tube and crest, but whereas the olfactory cells remain intercalated amongst the epithelial cells of the nasal mucous membrane, the auditory cells migrate a short distance away from the otic vesicle. A group of authorities believe that the neural crest contributes the formation of the whole of the vestibulocochlear nerve ganglion and hence this nerve can be regarded as a modified dorsal nerve. However, the olfactory nerves are restricted in all forms to the region of the head, whereas the vestibulocochlear nerve in man is the sole survivor of a whole series of nerves of the organs of the lateral line, which in lower forms are distributed to the head as well as to the whole length of the trunk. Therefore, the olfactory and the vestibulocochlear nerves may be considered as separate groups