ZOOACOR08T
UNIT – 07,Topic 1

COMPARATIVE ACCOUNT OF BRAIN IN VERTEBRATES

Introduction:

- In the metazoan body, nervous system functions as the mechanical coordinator.
- A gradual transition is evident in the nervous system, which is homologous to evolutionary chronology.
- How a simple nerve plexus evolved into a condensed and individualized C.N.S. is quite fascinating.
- As bilateral symmetry has evolved in animal kingdom, the necessity of coordinating the movement of the locomotor structures also arose. Concentration of the nervous elements occurred at the nervous elements. **This is referred to as cephalization.**
- Therefore, the head accommodates the anterior most specialized part of the nervous system.

Definition of Cephalization: It is the specialization of the anterior of an animal to form the head by the concentration in this region of feeding organs, sense organs, nerves etc. (Leftwich, 1983)

Position and Development:

- The brain of the vertebrates is situated within a box like structure i.e. The cranium. The cranium may be cartilaginous or bony.
- The brain communicates with posterior part of the CNS i.e. the spinal cord through the foramen magnum situated on the posterior part of the CNS. The cranial walls are also provided with a number of smaller foramina for the exit of the cranial nerves.
- The brain remains covered with a number of the thin coverings, the meninges.
- The brain, along with the spinal cord develops as a simple and hollow nerve tube early in the embryogenesis. It is ectodermal in origin.
- The neural ectoderm invaginates along a longitudinal axis and makes a shallow trough-like medullary groove, flanked by a neural or medullary fold on each side.
- The medullary folds opposing each other grow and finally fused together bringing about the closure of the neural tube. The overlying epidermal ectoderm becomes continuous after the closures.
- Afterwards, the anterior part of the neural tube differentiates as the brain with its characteristic unequal thickenings, evaginations and flexures.

Primary divisions of the brain:

- The entire nervous system of the vertebrate has two subdivisions – the central nervous system or CNS and the peripheral nervous system or PNS. The former includes the brain and the spinal cord, whereas the latter comprises various outflows of the CNS, viz. cranial nerves, spinal nerves and the autonomic nervous system.
- Embryologically the brain has three primary divisions – prosencephalon, mesencephalon and rhombencephalon. These subdivisions are subjected to various degree of modifications in different vertebrate groups and therefore, variously represented in adult brains. However, in a typical vertebrate brain following parts are discernible –

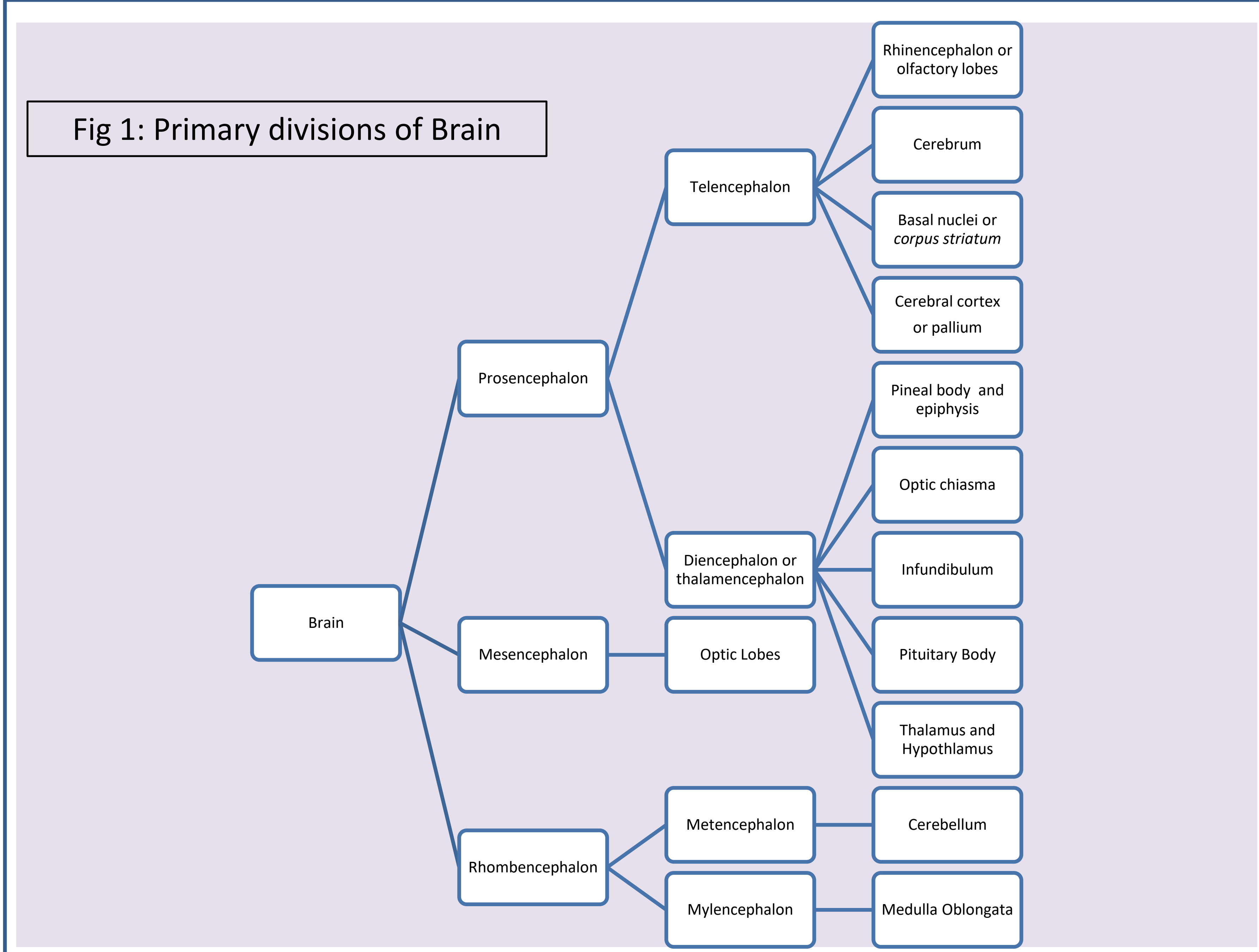


Fig 1: Primary divisions of Brain
Brain
Prosencephalon
Mesencephalon
Rhombencephalon
Telencephalon
Diencephalon or thalamencephalon
Optic Lobes
Metencephalon
Mylencephalon
Rhinencephalon or olfactory lobes
Cerebrum
Basal nuclei or *corpus striatum*
Cerebral cortex or pallium
Pineal body and epiphysis
Optic chiasma
Infundibulum
Pituitary Body
Thalamus and Hypothlamus
Cerebellum
Medulla Oblongata

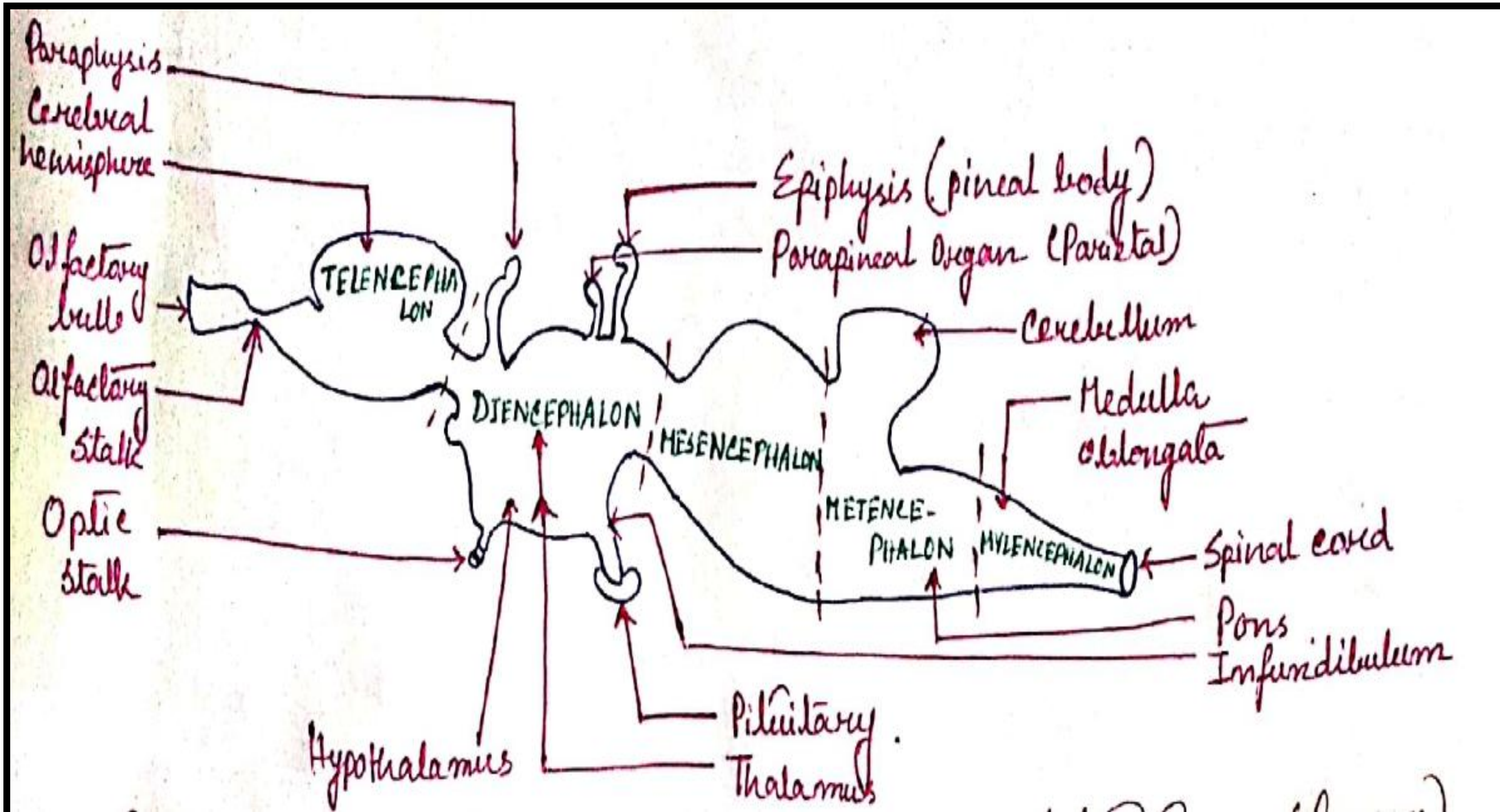


Fig 2: Various parts of an ideal vertebrate brain (after Romer & Person)

Modifications of Brain in General:

- The brain of chordates is basically an enlargement of anterior end of the neural tube. Among the living vertebrates *Latimeria* sp.(a coelacanth) has the smallest brain in relation to the body size and lies almost behind the hinge of the skull.
- In the primitive condition, the cell bodies, of the neurons, collectively called the gray matter are aggregated around the central canal or neurocoel. In the brain, however, the cell bodies migrate to take a more superficial position, as thus differ from the spinal cord in the disposition of gray matter and white matter comprising the processes of the cell body.
- The degree of development of the various parts of the brain of the vertebrates is largely correlated with their position in the evolutionary scale and with certain special requirements related to the particular environments in which they live.

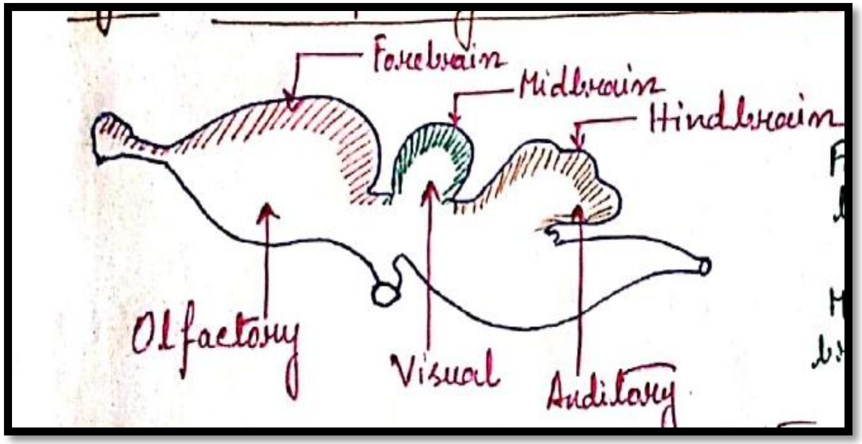


Fig3: Brain of primitive vertebrate

- The primary divisions of the brain might have developed in association with one of the three major senses, which still persists in all vertebrates.
- Thus the sense of smell is related to the prosencephalon, the sense of sight to the mesencephalon and the sense of hearing to the rhombencephalon (Weichert, 1970)

In different, groups of vertebrates, the brain is subjected to a good deal of modifications resulted from the following events:

1. Evaginations or invaginations of various portions of the primitive brain vesicles.
2. Folding or plaiting of the walls of different parts of the embryonic brain, thus increasing the brain surface.
3. Thickening of the walls in certain regions.
4. Failure of the thin-walled embryonic area to differentiate into the nervous tissue.
5. Bending or folding of the brain along its longitudinal axis designated as flexures.

Flexures in the brain:

Due to unequal rate of growth, during ontogenesis, certain flexures or bending occur in all vertebrates. Since, the brain lengthens much faster than other adjoining structures, the bending is apparently influenced by space limitations.

The following flexures are discernible:

1. Cephalic or cranial flexures: it occurs in the region of the mesecephalon in such a manner that the derivatives of the forebrain is bent downward at right angles to the rest.
2. Cervical or nuchal flexures: it develops near to the junction of the medulla oblongata and the spinal cord. The bend is in the same direction as the cephalic flexure.
3. Pontine flexures: it is formed in the region of the metencephalon and is opposite is direction to the other two.

Remarks: Cervical and pontine flexures are absent in the majority of the anamniotes, but might be evident in the embryonic life of amniotes. The cephalic flexures is permanently only in aves and mammals, particularly in the primates.

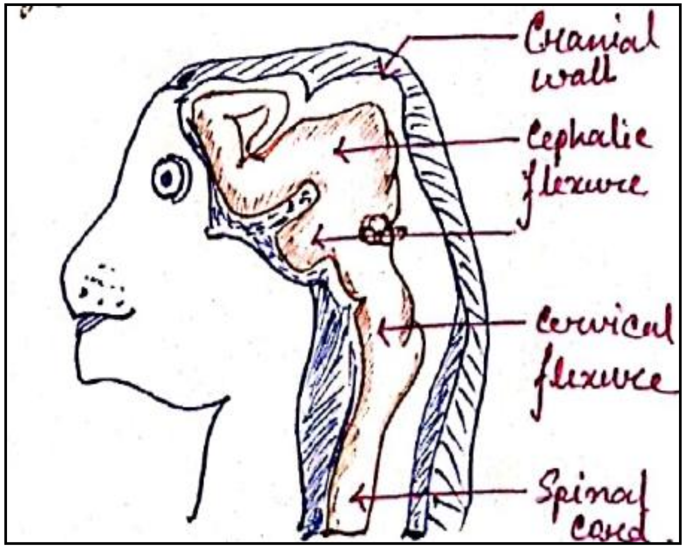


Fig 4: Sagittal section through the head of 18 day rat embryo showing flexures of brain (after Weichert)

Comparative account:

The architecture of the brain should be studied by first considering those parts, which are simplest in construction and bear a close resemblance to the spinal cord. In sensu scrito, the medulla oblongata presents a structure which is quite identical to that of the spinal cord.

A). Medulla oblongata or mylencephalon:

1. The medulla oblongata itself is basically similar to a section of the spinal cord, except that the central canal is greatly enlarged to form the 4th ventricle and its roof is the infolded to form the posterior choroid plexus.
2. Most of the cranial nerves from 5th to 12th arise from the medulla.
3. Columns of gray matter are found on either side of the 4th ventricle; arrangement of the columns is identical to that in spinal cord. A horizontal sulcus separates the dorsal sensory column from the ventral motor column.
4. In Cyclostomes the medulla is the part of the brain that is well developed. In Cyclostomes as well as in fishes and Urodele amphibians (i.e. Salmanders), a pair of giant or Mauthner's cells are found; their axons extend to the tail-muscles and are apparently concerned with execution of mascular contraction needed in swimming.
5. In some fishes a pair of conspicuous vagal lobes is present on the sides of the medulla representing the centers for the gustatory sense (taste). These lobes are absent in higher forms.

6. The dorsal anterior part of the medulla is referred to as the acoustic lateralis area containing nuclei (aggregation of cell bodies of the central nervous system) associated with nerves from the lateral line system. In terrestrial vertebrates this area is concerned only with the equilibratory and auditory functions of the air.
7. In mammals, there is an anterior swollen area, the pons, containing a great mass of neurones that relay impulses from hemispheres to cerebellum.
8. In lateral and ventral walls of the mylencephalon are thin but the dorsal wall is thick. The piamatterbecomes fused with the ependymal cells of the dorsal wall and forms the structure, called tela choroidea.

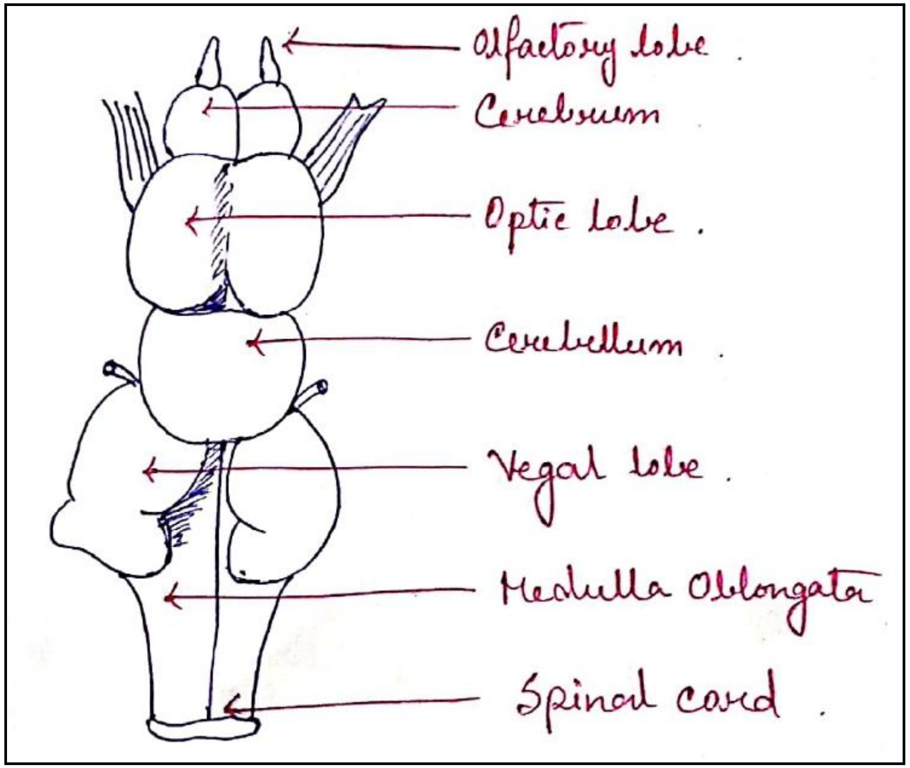


Fig 5: Vegal lobes in Buffalo Fish (*Carpiodes tumides*) brain.

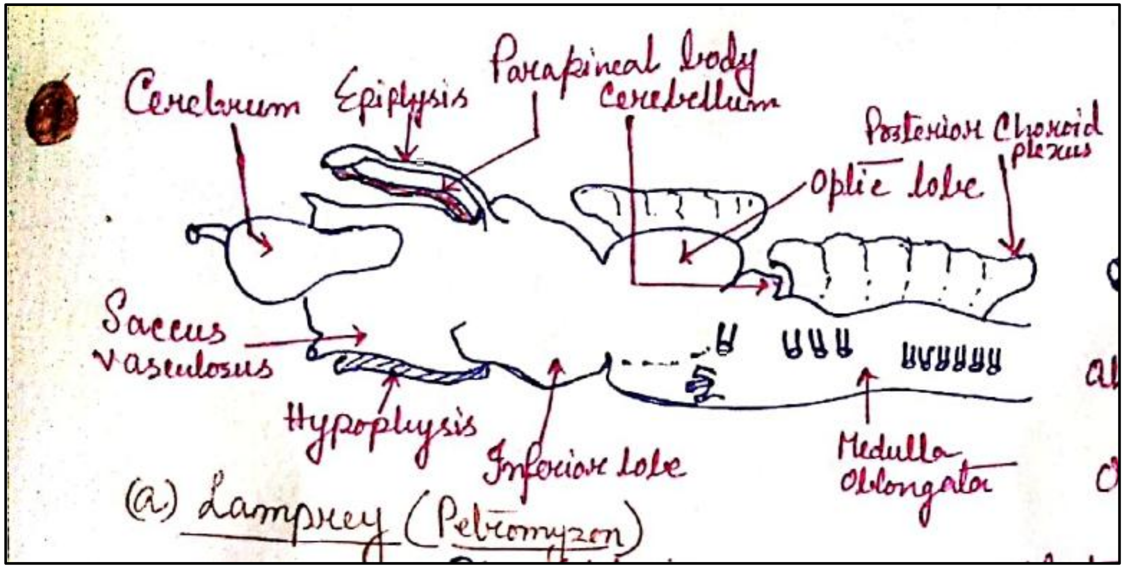
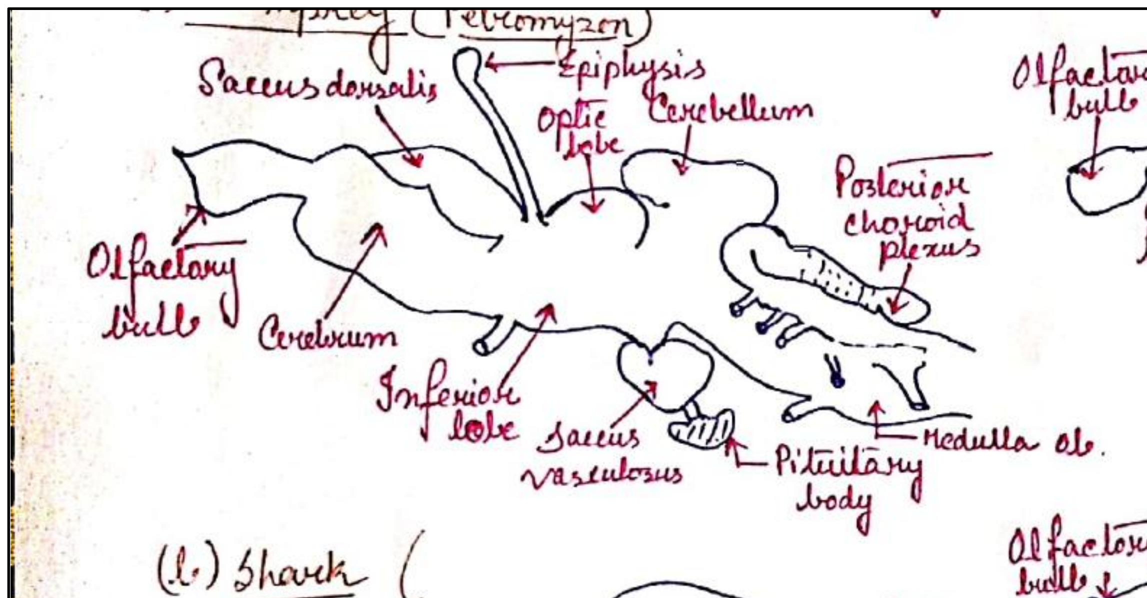
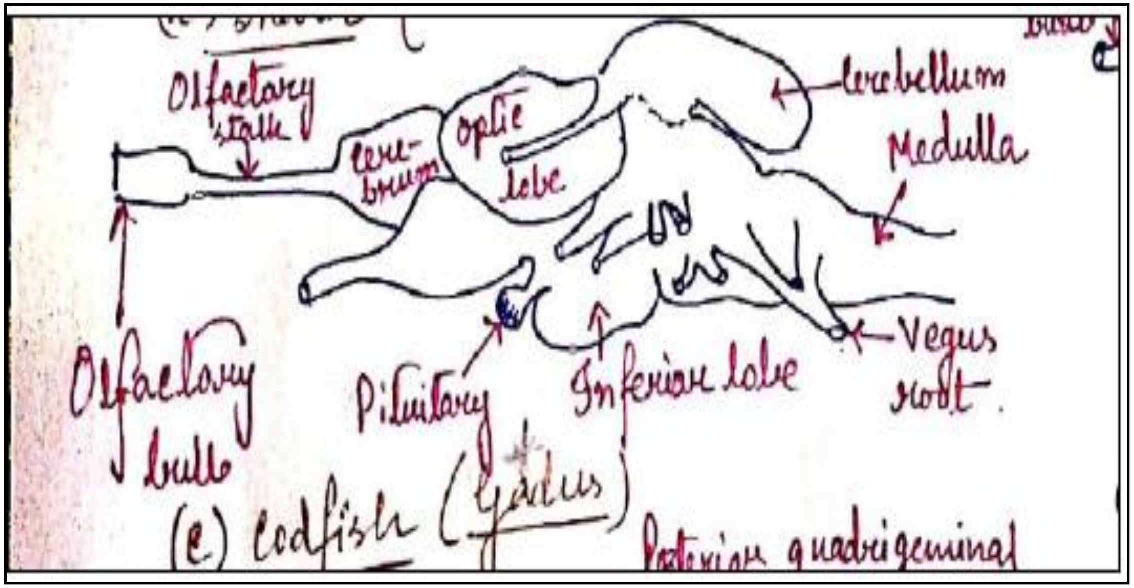


Fig 6: a-h. Brains of different vertebrates (lateral view)





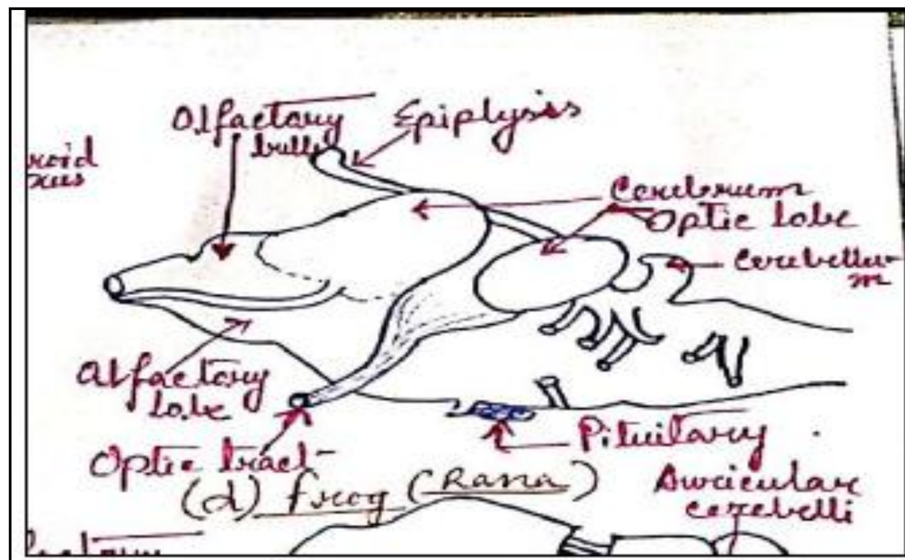


Fig 6: a-h. Brains of different vertebrates (lateral view)

B) Metencephalon:

1. The dorsal part of the metencephalons elevated to form cerebellum. The function of this part of the brain is to coordinate the neuro-muscular mechanism of the body.
2. In Cyclostomes, Sluggish fishes and amphibians the cerebellum is poorly developed. In these form it is more or less a transverse shelf or ridge bordering the anterior edge of the tela choroidea of the mylencephalon.
3. In active fishes, such as most elasmobranches and few teleosts the cerebellum is a prominent structure, extending and partially overlapping the mesencephalon anteriorly and mylencephalon posteriorly.
4. The cerebellum encloses a cavity, the metacoele, which is connected with the myelocoele (4^{th} ventricle) with a narrow cerebellar aquedact.
5. In elasmobranchs, a shallow median groove as transverse grooves render the cerebellum a lobed appearance. In lower vertebrates, the ventral portion is composed of heavy fibre-tracts, which merge with those of the medulla oblongata.
6. At the antero-lateral angles of the medulla, in certain fishes, such as elasmobranchs, chondrosteans (sturgeous) and dipnoans (the lung fishes) prominent irregular project auricle contains a cavity the auricular recess that is continuous with fourth ventricle. These are centres of equilibration.
7. In retiles, cerebellum is rather ill-developed and simple in structure; being much better developed in swimming forms like turtles. But in crocodiles, it is with a pair of small lateral floceular lobes, corresponding with the auricular lobes of fishes.

8. In birds, the cerebellum is highly developed, transversly grooved and consists of a prominent middle portion, the vermis and lateral well developed flocular lobes. The cerebellum extends posteriorly to cover the tela choroidea of the medulla.
9. The cerbellar cortex of birds comprises of complexly branched neurons (i.e. the gray matter) called the arbor vitae. In some birds a bridge of nerve fibres, the pons is developed that connects the cerebral cortex with cerebellum.
10. The mammalian cerebellum is best developed among the vertebrates. The vermis is divided into anterior, middle and posterior part as in the birds. The middle lobe of the vermis has lateral extensions the cerebellar hemisphers, and the flocular lobes are much larger.
11. The surface of the cerebellum is folded with ridges, the gyri and the deep grooves, the sulci . The ventral portion has prominent mass of transverse nerve fibres, the pons. In mammals, the equlibration center is celebration cortex instead of the cerebellum.
12. In mammals, the cerebral cortex consists of the following the three layers:
    a) an outer molecular layer with few cells with sparsely medullated fishes.
    b) a middle or interminent layer with few complexly branched Perkinje cells and
    c) an internal granular or nuclear layer composed of the cell bodies of small nerve cells.

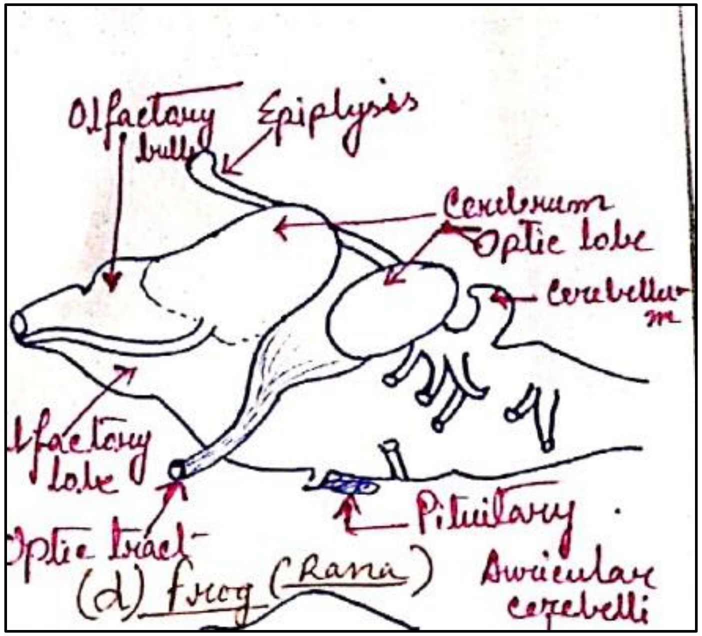
Remarks: The Perkinje cells are believed to play an important part in the process of correlating nerve impulses with equilibratory muscular movemnts (Weichert, 1970)

C) Mesencephalon:

1. This portion of the brain remains relatively undifferentiated and remains separated from the hind brain by a prominent constriction, the isthmus.
2. The floor and the walls of the mesencephalon are thick and composed of fibre tracts, the cerebral peduncles connecting this part with fore- and hindbrain. The roof consists of the thick layer of gray matter, the optic tectum.
3. Fishes of a particular quadrant of retina have been found to go preferentially towards specific areas of the tectum. In this area, the nerve cells are found to be arranged in layers, some what similar to those of the cerebellar cortex.
4. In the lower vertebrates two dorsal prominences, the optic lobes or corpora bigemina develop on the roof. These lobes have large optic ventricles, constituting the mesocoele together in the lower forms but the lobes are practically solid in the higher forms.
5. In snakes and mammals, a transverse fissure divides the optic lobes into four prominences, the corpora quadrigemina. The anterior pair of lobes is called superior colliculi containing receptive centres for the visual sense and the postrior pair is called inferior colluculi that serves to integrate auditory impulses.
6. In birds, the optic lobes are unusually well developed in correlation with the highly organized visual sensory system, which is necessary to animals in flying and feeding.
7. At the anterior end of the roof of the brain, the posterior commissure consisting of fibre tracts connecting the two side of the brain, is found. Some of its fishes are probably derived from the diencephalon.

Remarks:

It is noteworthy that a vascular choroid plexus is present in mid-dorsal part of the mesencephalon in cylostomes (Weichert, 1970)



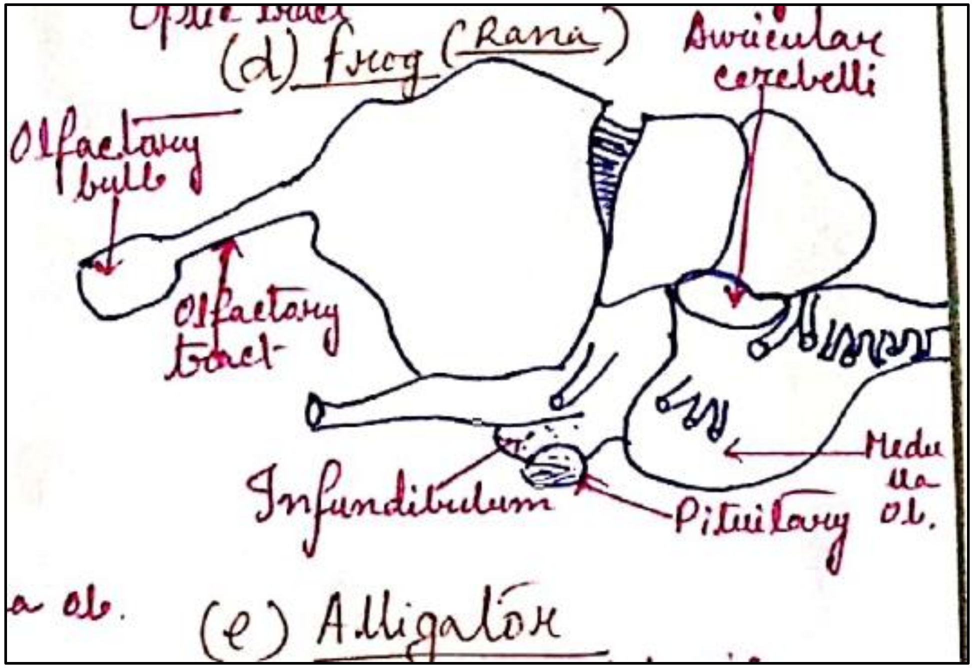
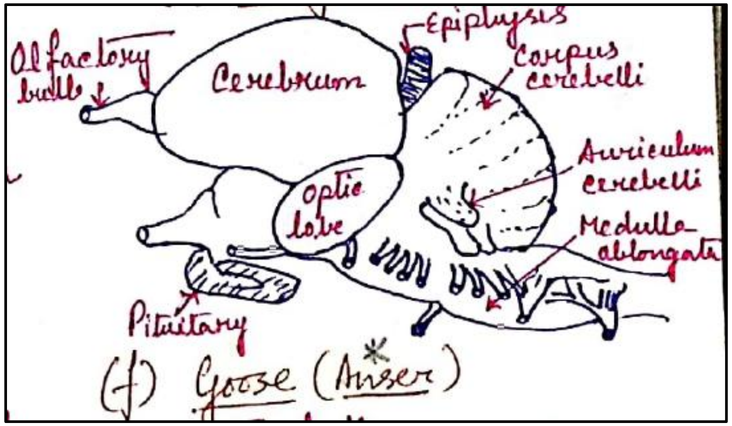
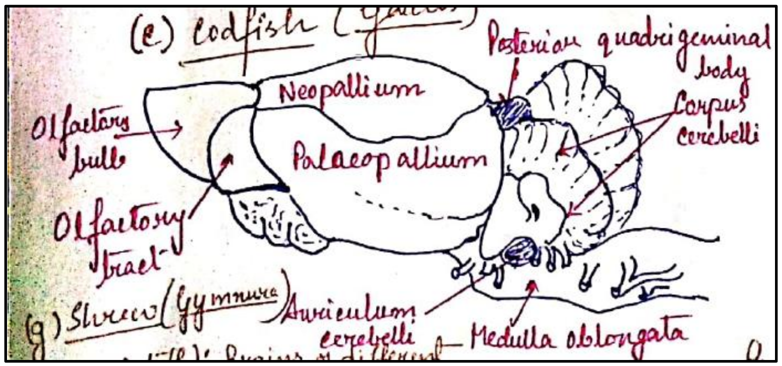
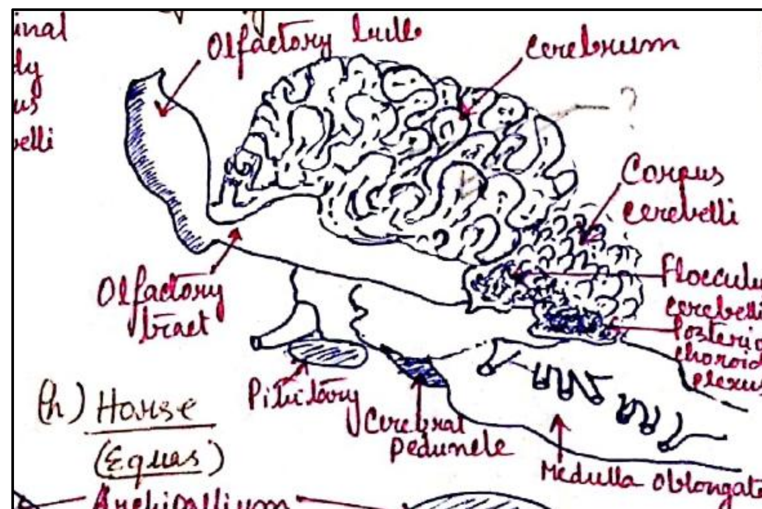


Fig 6: a-h. Brains of different vertebrates (lateral view)







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D) Diencephalon: It is marked off by an anterior-dorsal fold -- the velum transversum from the telencephalon and encloses the third ventricle. It is divisible into a dorsal epithalamus, a median very thick thalamus and a ventral thinner hypothalamus.

a) Epithalamus:

1. The dorsal roof retains its original epithelial ependymal nature and together with the pia matter forms a tela choroidea (similar to that covering the 4^{th} ventricle). Vascular folds the tela extend into the 3^{rd} ventricle forming the anterior choroid plexus.
2. A prominent irregular fold of the tela choroidea, called the paraphysis extends dorsally from its anterior end. Since it lies anterior to the velum transversum, it is sometimes referred to as a part of the telencephalon. Its function is unknown and usually disappears in the adult life.
3. In *Ambystoma mexicanum* the paraphysisproduces glycogen that passes into the ventricular cerebro-spinal fluid. In lower forms certain other vascular folds of the anterior choroid plexus are found in addition to the paraphysis.
4. Posterior to the tela choroidea, the spiphyseal apparatus is situated. It consists of an anterior parapineal or parietal body and posterrior pineal body or epiphysis.
5. The parapineal body, when well developed, forms a small median eye-like structure. In many lizards, such as *Sphenodon punctatum*, a small lens and retina are even present. In frog, its position is marked by a brown spot or frontal organ.
6. The pineal body is usually considered to represent the remnant eye-like structure. Only inlapreys, however, both parapineal as well as pineal organs are associated with snake structures. The pineal body is present in all vertebrates and appeared to be glandular in nature.
7. It seems that in lower vertebrates, the parapineal and pineal organs contain photoreceptive elements, whereas in the higher forms, the pineal body has become a parenchymal mass of tissue . E.M. Studies have revealed the presence of many cells similar to rods and cons in the parapineal organs of lamprey, tadpoles and lizards.

8. A pair of habenular bodies lies front of the pineal body which are connected by a delicate habenular commissures. The epithalamus is of relatively little significance as a nerve centre.

b) Thalamus:

1. The thickened lateral portion of the diencephalon is known as thalamus. It is divided into dorsal and ventral parts and contains relay centres, represented by many nuclei.
2. The dorsal nuclei are chiefly concerned with the sensory impulses and the ventral nuclei with the motor impulses.
3. In reptiles and mammals, the walls of the thalamus are thickened inwardly so as to meet in the centre of the 3^{rd} ventricle and connecting mass of gray matter is called soft commissure.

c) Hypothalamus:

1. The hypothalamus is composed of four main parts: the optic chiasma, tuber cinereum, mammillary bodies and the infundibulum.
2. The optic chiasma is formed by the crossing of the two optic nerves; tuber cinereum and mammillary bodies contain nuclei of parasympathetic and olfactory centers. The distal part of infundibulum forms the posterior lobe or pars nervosa of the pituitary body.
3. In fishes and salamanders, a pair of inferior lobe is present on either side at the base of infundibulum. The distal end of infundibulum, in these forms enlarged into a vascular sac ,the saccus vasculosus,of unknown function. It is best developed in deep sea fishes.

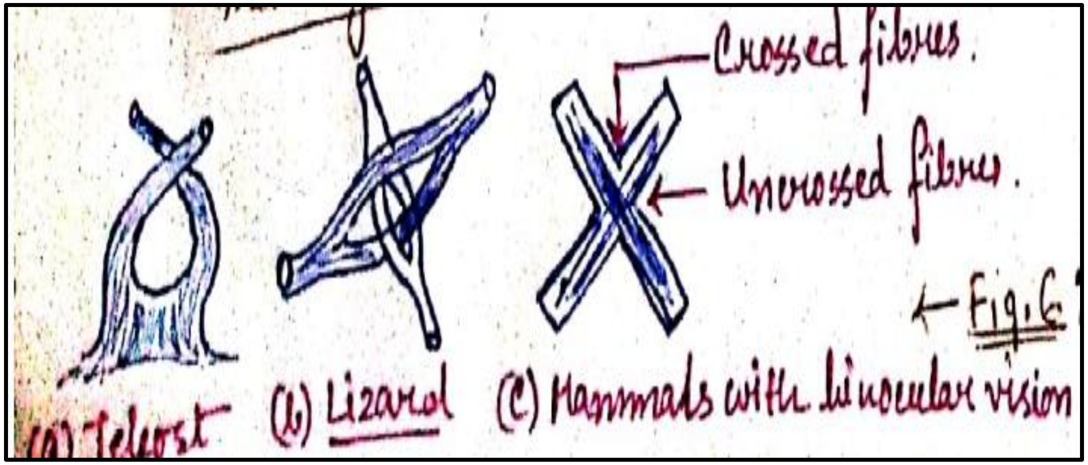


Fig.7: Optic chiasma in different group

E) Telencephalon

1. It is divisible into an anterior olfactory lobe or rhinencephalon and a cerebrum. An anterior commisures connecting the olfactory regions of the two halves is located in the lamina terminalis.
2. The olfactory lobes are located just behind the olfactory apparatus. In the forums where the mares are situated at a distance from the brain, the olfactory lobes are divided into anterior olfactory bulb and posterior narrow olfactory stalk or tract.
3. The floor of the cerebrum, generally comprising the two hemispeheres, is thick and called the corpus striatum and its roof is called pallium. The gray region of the corpus straitum is called basal nuclei; the function of the regions is unkown. The cerebral hemispheres enclose lateral ventricles.

4. The cerebral hemispheres of cyclostomes are chiefly olfactory and those of teleosts are small. The hemispheres are, however, more pronounced in elasmobranchs; and in the higher tetrapods they are voluminous.
5. The pallium is thin in fishes but in amphibians, the pallium is divisible into a dorso-medial archipallium and a more lateral paleopallium. In reptiles, the hemispheres are still larger partially cover the diencephalon posteriorly.
6. In certain advanced reptiles, a new area, the neopallium develops in between archi- and paleopallium, on the outer part of the hemispheres.
7. In crocodiles, nerve cells migrate to the neopallium region and in mammals, this region becomes much more thick to form the cerebral cortex. In man, the cortex is comprised of about 10 billion cells and about 100 billion neuroglial cells, arranged in 6 layers.
8. In birds, archi- and paleopallium are found but neo pallium seems to be lacking. The corpus striatum or hyper striatum is exceptionally thickened and in *Columba* it is divisble into epi-, meso- and hypostraitum.
9. In mammals, the cerebral surface is thrown in to folds with ridges or gyri and deep furrows, the sulci. Deep fissure divided the mammalian hemispheres into distinct lobes: frontal, parietal, temporal and occipital.
10. A transverse band of white or medullated fibres called corpus callosum is found in marsupials and eutheria that connects the neopallium of the two sides.

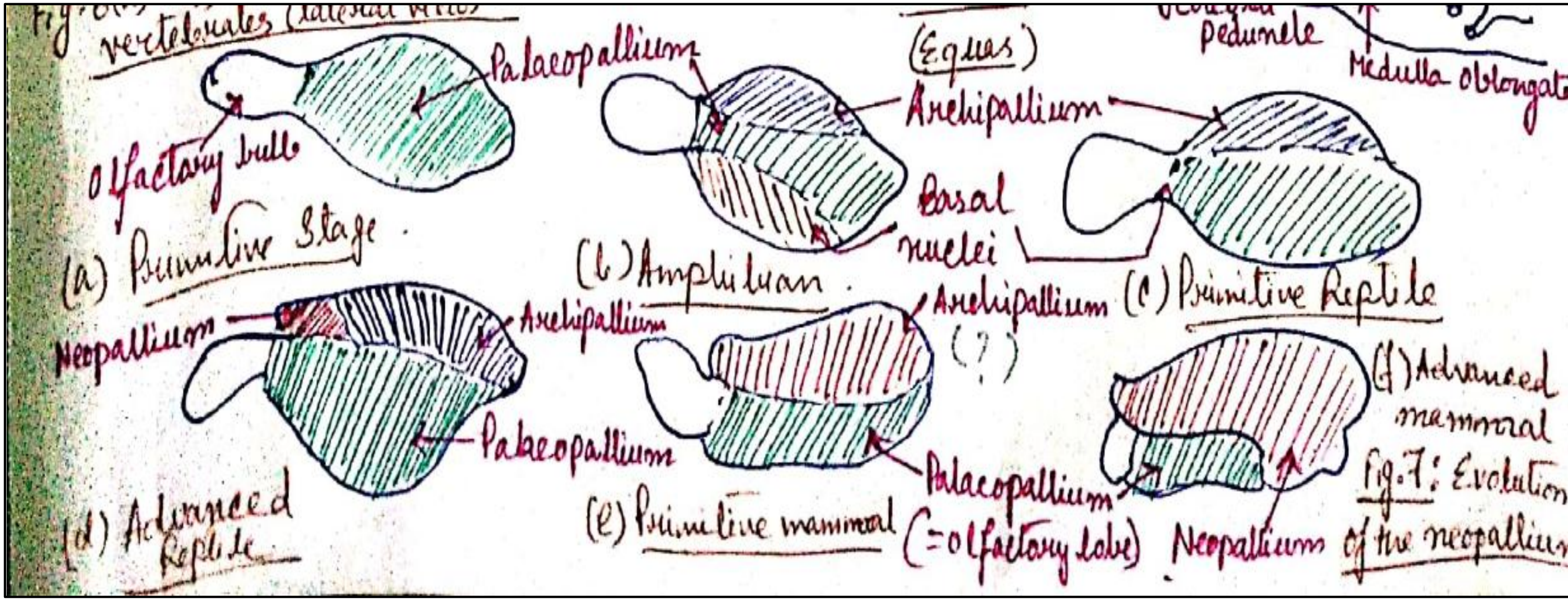


Fig8: Evolution of the Neopallium

11. Owing to the great expansion of neopallium in the mammals and particularly in human, the archipallium is pushed to a ventromedial position and the paleopallium also to be a ventral position. The former becomes the hippocampal lobe and the latter the pyriform lobe, a portion of the olfactory lobe.
12. Beneath the gray matter lies medulla of the cerebral hemispheres composed of nerve fibres. Ventral to corpus callosum is another band of white fibres, the fornix that connects the hippocampal lobes with the hypothalamus.

Meninges of the brain :

Brain is covered with membranes, called meninges. In cyclostomes and fishes, asingle membrane, the meninx primitiva clothes the brain. In urodeles, there are two membranes, the inner pia mater and the outer dura mater. In mammals, a third layer, the arachnoid layer is interspersed in between the two layers.

Ventricles of the brain:

The neurocoel in the brain expand to form ventricles. There are four ventricles: the first two are called lateral ventricles found inside the cerebral hemispheres; the third in the diencephalon and the fourth in the medulla oblongata. The lateral ventricles cmoounicate with the third through the foramen of Monroe, while the aqueduct of Sylvinus connects the third ventricle with the fourth.

Ventricles remain filled with cerebrospinal fluid (CSF). Three opening – a median foramen of Magendie and paired lateral foramen of Luschka, serve for the passage of the CSF into the subdural space.

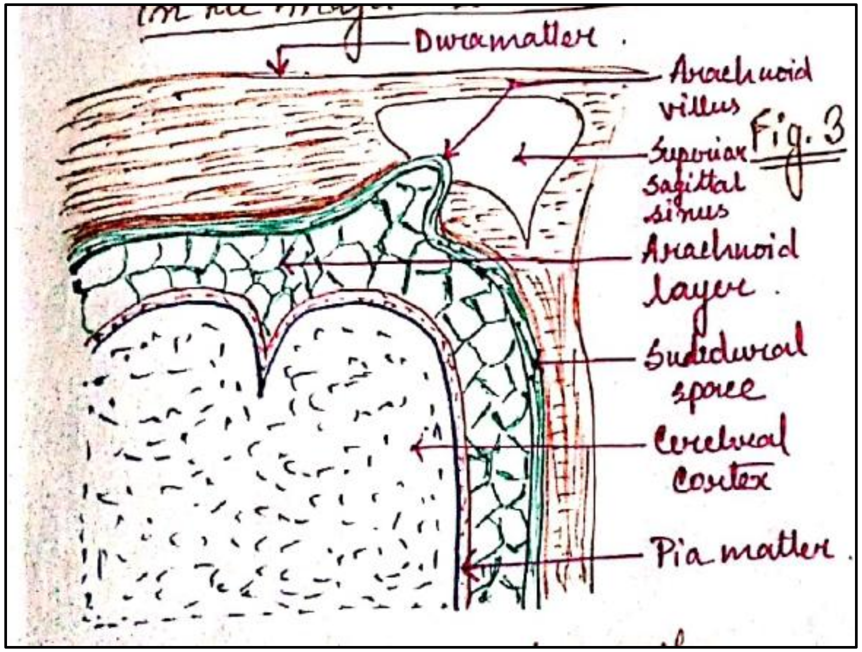
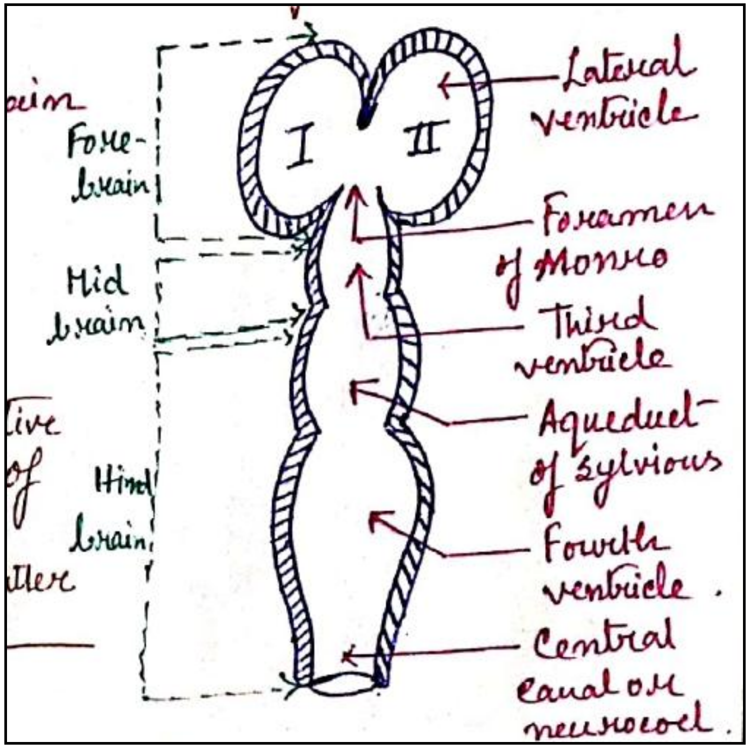


Fig.9 : T.S. Of a mammalian brain showing the meninges

Fig.10: Position of ventricles in a brain



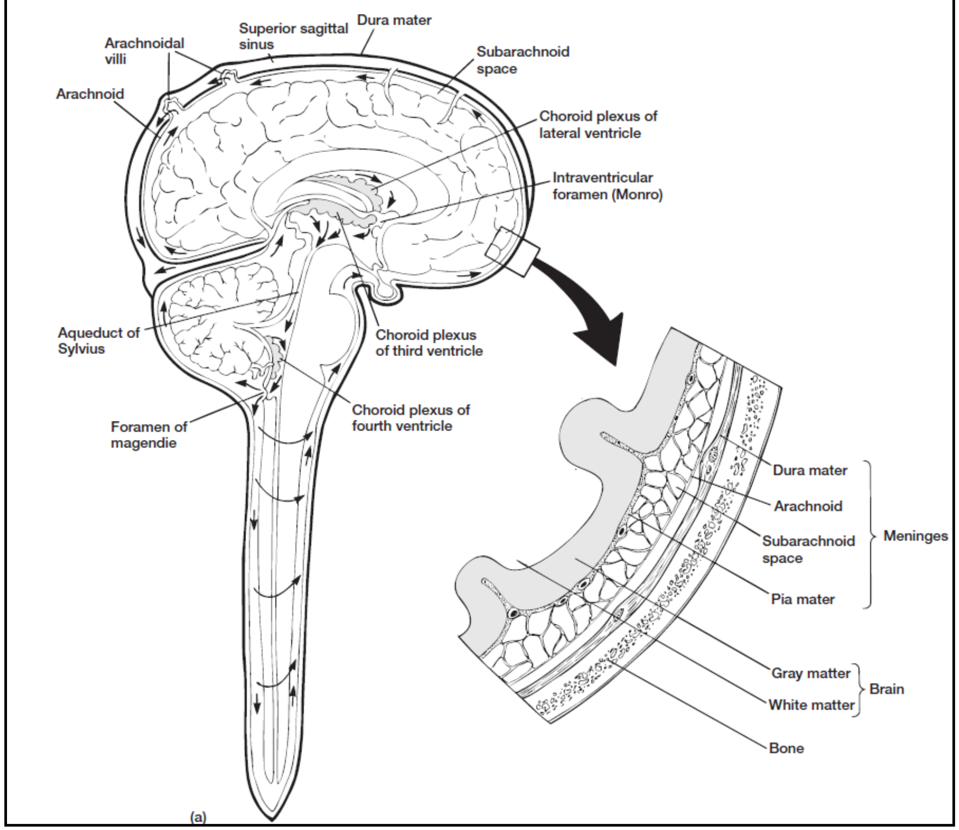
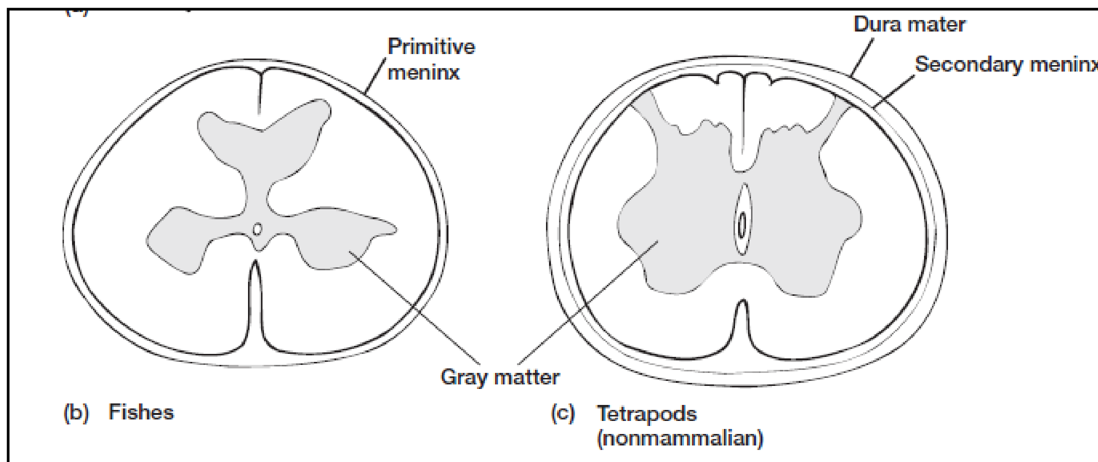


Fig. 11: Meninges: (a) Arrows trace the circulation of cerebrospinal fluid through the brain and spinal cord of a mammal. The triple-layered meninges are enlarged to the right. (b) The meninges of fishes consist of a single thin layer,the primitive meninx. (Source: Kardong, 2011)

Fig.11(c): In all tetrapods except mammals, the meninges are double layered and consist of an outer dura mater and inner secondary meninx. (Source: Kardong, 2011)



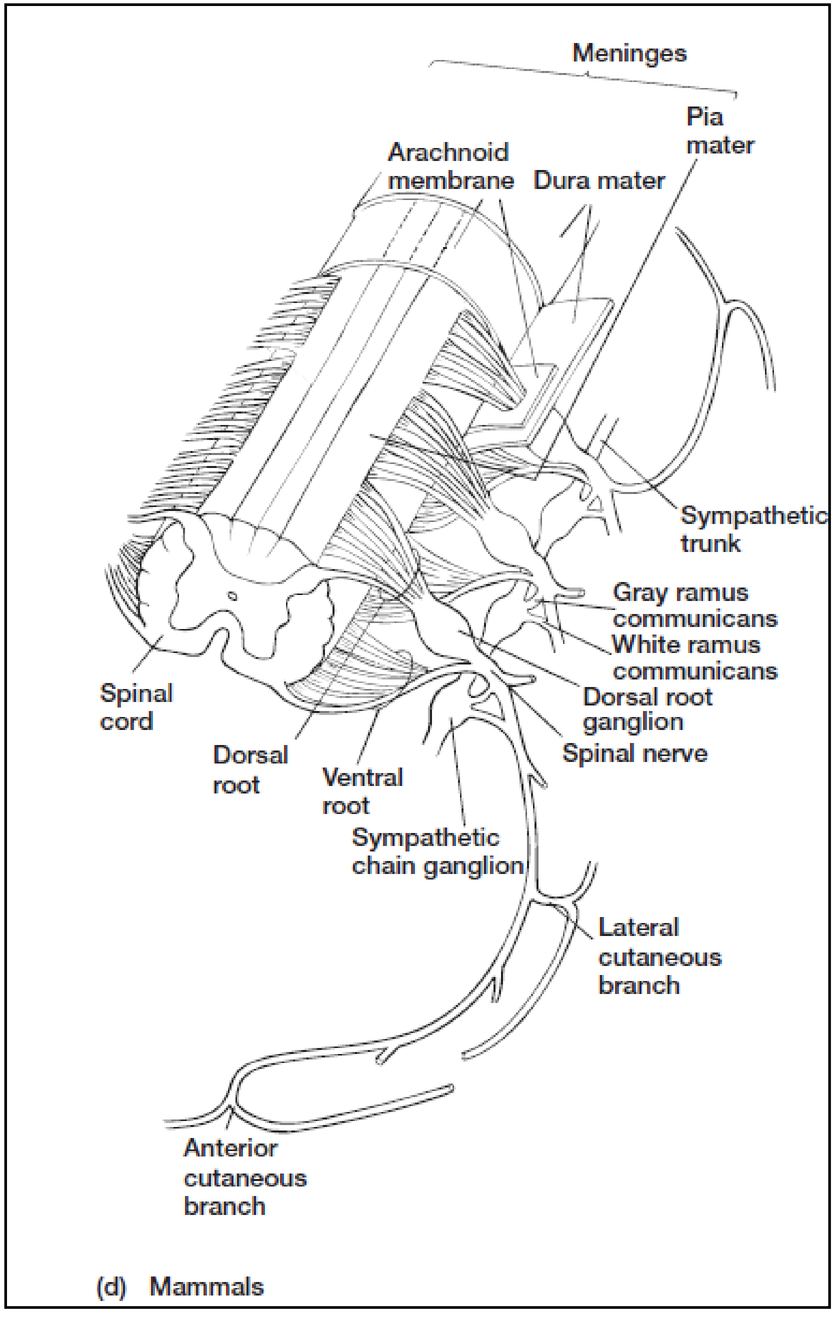


Fig.11(d): Cutaway section of the spinal cord in a mammal illustrates the three meningeal layers: dura mater, arachnoid, and pia mater. Branches of the spinal nerve are shown along with their connections to the sympathetic chain. (Source: Kardong, 2011)

Bibliography:

1. Jollie, M. (1962): Chordate Morphology;
2. Weichert, C.K. (1970): Anatomy of the chordates;
3. Hildebrand,M.(1974): Analysis of Vertebrate Structure;
4. Romer, A.S. & Parsons, T.S. (1978): The Vertebrate Body;
5. Kent, G.c. & Carr, R.K.(2001): Comparative anatomy of the Vertebrates ;
6. Kardong, K. (2011):Vertebrates – Comparative Anatomy, Function, Evolution.

DISCLAIMER: The author wishes to express his indebtedness to late Dr. Swapan Kumar Das for the text of this study material and also to Ms. Sukanya Paul for the illustrations.