ORGANIZATION OF OLFACTORY SYSTEM, FOREBRAIN AND PITUITARY GLAND OF A TELEOST, *NOTOPTERUS NOTOPTERUS*

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Abstract

Nuclear identification of olfactory system, forebrain and pituitary gland in *Notopterus notopterus* (order - Osteoglossiformes) is studied using Klûver and Barrera and Aldehyde fuschin staining techniques. Olfactory system has a short olfactory nerve which connects the olfactory epithelium with the bulb. From the bulb, two tracts run posteriorly and enter the telencephalon. In the olfactory bulb, mitral cells and giant cells of nervus terminalis (NT) are observed. In the forebrain, near the lateral forebrain bundle (LFB), multipolar cells of nucleus entopeduncularis (NE) are located in the telencephalon. Diencephalon is divided into preoptic area, hypothalamus, thalamus and epithalamus. In the diencephalon, Suprachiasmatic nucleus (SCN), Nucleus preopticus (NPO) and nucleus anterior commissure (NAC) are also identified. In the preoptic area, nucleus of subventricular gray (NSG) and organasum vasculossum lamellae terminalis (OVLT) is observed. Nucleus preopticus magnocellularis (NPOm) is the only AF-positive nucleus in the neuronal complex. Caudal to preoptic region, the tuberal area starts which has nucleus hypothalmicus (Nh) and nucleus lateralis tuberis (NLT). Above the hypothalamus, thalamic area shows thalamic nuclei. In the epithalmus, paired habenular ganglia are connected to each other by habenular commissure. Pituitary is platybasic which has flat neurohypophysis and disc shaped adenohypophysis.

Key words : Cytoarchitecture, Osteoglossiformes, Olfactory organ, Forebrain.

Introduction

Teleosts represent the most abundant group of bony fishes covering about 28,400 species (1). Pisces is phylogenetically the oldest vertebrate group holding large number of species with distinct morphological variations. These morphological variations have arisen as result of the diverse environments that they inhabit. They occupy a variety of freshwater and marine habitats and display a wide range of structural and functional responses to these environments.

In the early periods of brain research, the only neurosecretory neurons known in the brain were those of the nucleus preopticus; later, other neurons in the hypothalamus and recently other areas of the brain were also found to have this quality and such neurons. For studying the neurobiology of any brain area, it is a basic requisite to understand the morphological organization of the area by various neuroanatomical techniques.

Cytoarchitectural analysis appears to be the widely accepted criteria to study the organization of the neuronal groups in the brain of teleosts (2-10).

Although, information about the importance of olfactory organ, forebrain and pituitary gland in the regulation of reproduction is available, no reports are available on the cytoarchitectonic pattern of osteoglossiformes though it is a important and major order in the teleosts among the indigenous fishes. The fish *N. notopterus* selected for the present study is common in lakes throughout the greater parts of India. Its unique feature related to reproduction is the presence of single gonad in the body. The cytoarchitectonic pattern of the olfactory organ, forebrain and pituitary of *N. notoptersus* is explored using standard techniques at light microscopic level.

Materials and Methods

Notopterus notopterus is found in clear streams and enters the brackish waters. It inhabits standing and sluggish waters of lakes, floodplains, canals and ponds, feeds on insects, fish, crustaceans and some young roots of aquatic plants. It is active during twilight and night, colonizes and breeds seasonally during rainy days and migrates back to permanent waters in dry season.

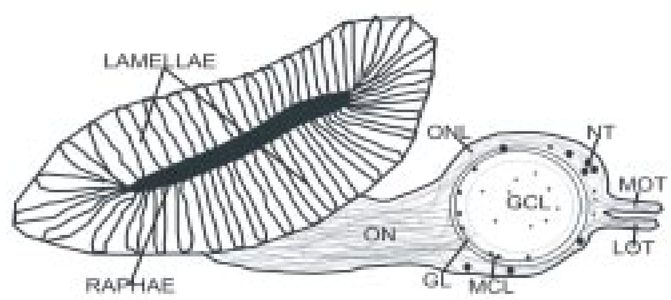

Fig.1 . Diagrammatic representation of the saggital section of the olfactory system of *N. notopterus* showing, GCL, granular cell layer; GL, glomerular layer; MCL, mitral cell layer; MOT, medial olfactory tract; ON, olfactory nerve; ONL, olfactory nerve layer.

Collection and maintenance of fish: Fishes were collected from natural habitat all around the Nagpur City. They were brought to the laboratory and acclimatized in small ponds. Sexually matured fishes were selected with body weight ranging between 75 gm to 125 gm and length 15 to 20 cm.

Histological Methods: Fishes were anaesthetized with 0.2% 2-phenoxy ethanol. They were perfused transcardially with 150-200 ml ice cold phosphate buffered saline (PBS, pH 7.45),

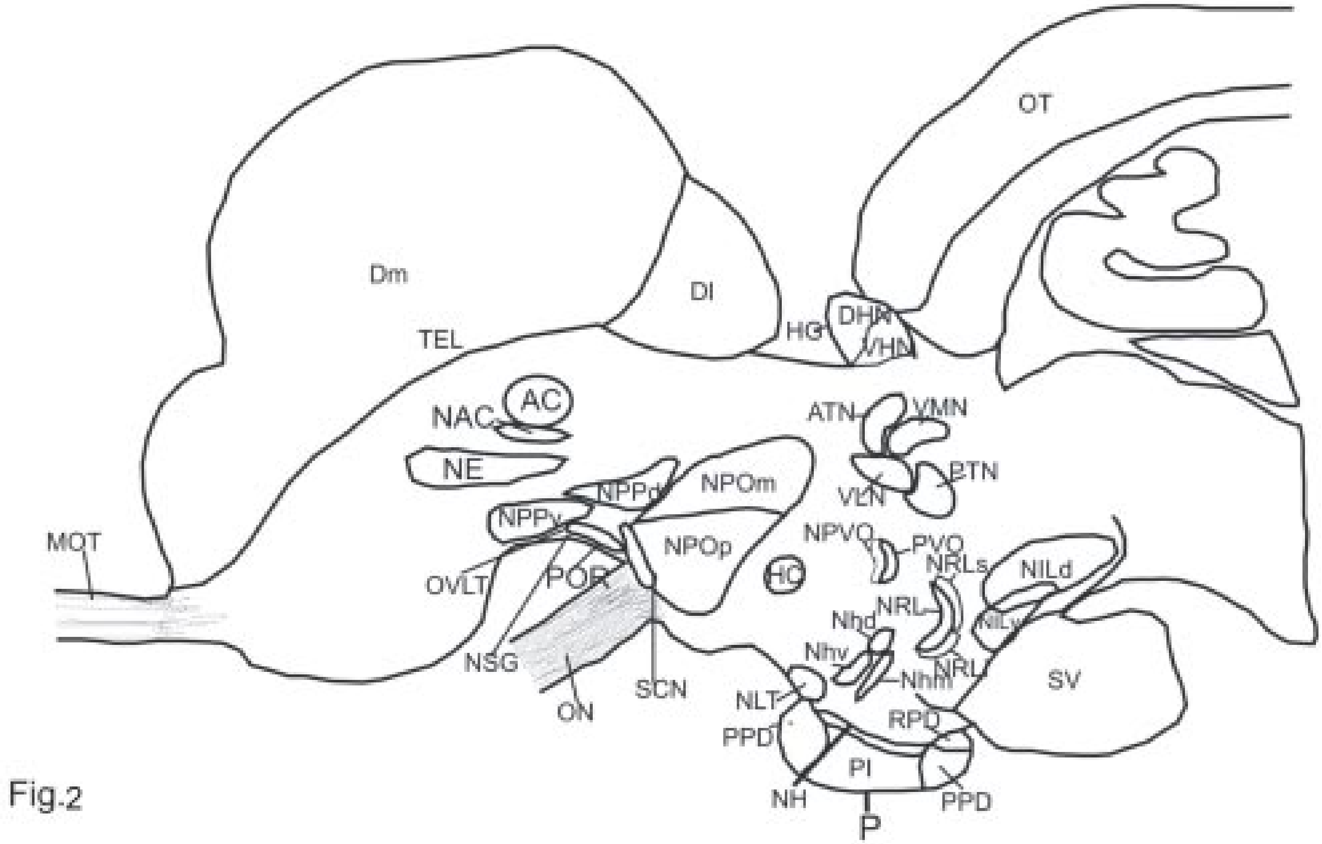

Fig. 2. Diagrammatic representation of the saggital section of forebrain and pituitary gland of *N. notopterus* showing, AC, anterior commissure; ATN, anterior thalamic nucleus; Dm, area dorsalis telencephali pars medialis; DHN, dorsal habenular nucleus; Dl, pars lateralis ; HC, horizontal commissure; HG, habenular ganglion; MOT, medial olfactory tract; NAC, nucleus of anterior commissure; NE, Nucleus entopedencularis; NH, Neurohypophysis; Nhd, nucleus hypothalamicus dorsalis; Nhm, nucleus hypothalamicus medialis; Nhv, nucleus hypothalamicus ventralis; NILd, nucleus inferior lobi pars dorsalis; NILv, nucleus inferior lobi pars ventralis; NLT, nucleus lateralis tuberis; NPOm, Nucleus preopticus pars mangnocelularis; NPOp, nucleus preopticus pars parvocellularis; NPPd, nucleus preopticus periventricularis dorsal; NPPv, nucleus preopticus periventricularis ventral; NPVO, nucleus paraventricular organ; NRL, nucleus recess lateralis; NRLi, nucleus recess lateralis inferior; NRLs, nucleus recess lateralis superior; NSG, nucleus of subventricular gray ;ON, optic nerve ;OT, optic tectum; OVLT, organum vasculosum laminae terminalis; P, pituitary gland; PI, pars intermedia; POR, preoptic recesses; PPD, proximal pars distalis; PTN, posterior thalamic nucleus; PVO, paraventricular organ; RPD, rostral pars distalis; SCN, suprachiasmatic nucleus; SV, saccus vasculosus; TEL, telecephalon VHN, ventral habenular nucleus; VLN, ventrolateral thalamic nucleus; VMN, ventro medial thalamic nucleus

followed by the same volume of ice-cold Bouin's fixative. Olfactory organ with bulb and brain with pituitary gland were dissected out and post-fixed in the same fixative overnight.

Tissues were dehydrated in graded series of alcohol, cleared in xylene and embedded in paraffin wax. The olfactory organ and brain with pituitary gland were cut at 10 mm thickness in transverse as well as sagittal plane.

Staining techniques

Klüver and Barrera technique: The sections of olfactory organ with bulb and brain with pituitary were deparaffinised in xylene and passed through different grades of alcohol upto 95% alcohol(11). They were stained in 0.1% solution of Luxol Fast Blue in 95% alcohol for 6 to 8 hours at 570C. Sections were rinsed in 95% alcohol to wash off the excess stain and brought down to distilled water through descending grades of alcohol, differentiated quickly in 0.1% Lithium carbonate solution and passed through several changes of 70% alcohol till there was a sharp contrast between the greenish blue white matter and colourless gray matter. Sections were washed thoroughly in distilled water and stained in 0.1% cresyl violet solution for 2 hours then differentiated in several changes of 95% alcohol, dehydrated, cleared in xylene and mounted in DPX and coverslipped.

Aldehyde Fuschin (AF): The deparaffinized sections of brain and pituitary were passed through descending grades of alcohol, brought to water and oxidized for 1 minute in 0.3% potassium permanganate solution acidified with sulphuric acid. They were decolorized quickly in 0.1% sodium metabisulphite. The sections were rinsed in distilled water and 70% alcohol, and then stained in AF stain containing paraldehyde, concentrated hydrochloric acid and basic fuschin in 70% alcohol, dehydrated and mounted in DPX after clearing in xylene.

Results

Olfactory system: In, *N. notopterus*, paired olfactory organs

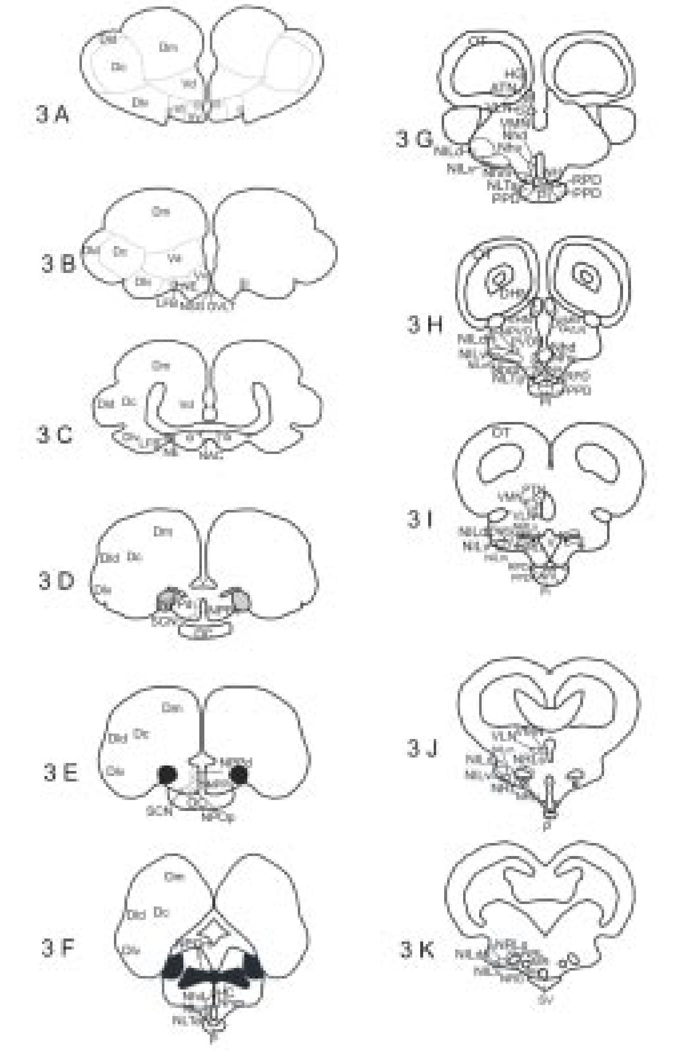

Fig. 3 A - K. Diagrammatic representation of the transverse section of the forebrain of *N. notopterus* showing, Dc, area dorsalis telencephali pars centralis; DHN, dorsal habenular nucleus; Dld, area dorsalis telencephali pars lateralis dorsalis ; Dlv, area dorsalis telencephali pars lateralis ventral; Dm, area dorsalis telencephali pars medialis; HC, horizontal commissure; HG, habenular ganglion; LFB, lateral forebrain bundle; MN, mamillary nucleus; MR, mamillary recess ;NAC, nucleus of anterior commissure; NE, Nucleus entopeduncularis; NH, Neurohypophysis; Nhd, nucleus hypothalamicus dorsalis; Nhv, nucleus hypothalamicus ventralis; Nhm, nucleus hypothalamicus medialis; NILd, nucleus inferior lobi pars dorsalis; NILm, nucleus inferior lobi pars medialis; NILv, nucleus inferior lobi pars ventralis; NLTa, nucleus lateralis tuberis pars anterior; NLTp, nucleus lateralis tuberis pars posterior; NPOm, nucleus preopticus pars mangnocelularis; NPOp, nucleus preopticus pars parvocellularis; NPPd, nucleus preopticus periventricularis dorsal; NPPv, nucleus preopticus periventricularis ventral; NPVO, nucleus paraventricular organ; NSG, nucleus of subventricular gray; NRL, nucleus recesses lateralis; NRLi, nucleus recesses lateralis inferior; NRLs, nucleus lateralis recesses superior; OC, optic chiasma; OT, optic tectum; OVLT, organum vasculosum laminae terminalis; P, pituitary gland; PI, pars intermedia; PPD, proximal pars distalis; PTN, posterior thalamic nucleus; PVO, paraventricular organ; RPD, rostral pars distalis; SCN, suprachiasmatic nucleus; SV, Saccus vasculosus;V, ventrical; Vd, area ventralis telencephali pars dorsalis; VHN, ventral habenular nucleus; Vl, area ventralis telencephali pars lateralis; VLN, ventrolateral thalamic nucleus; VMN, ventromedial thalamic nucleus. Vv, area ventralis telencephali pars ventralis.

with short olfactory nerve attached with the bulb are located in the snout region enclosed by a skin flap which is connected to the forebrain by medial olfactory tract (MOT) and lateral olfactory tract (LOT) (Fig. 1).

It has a single common inlet and outlet to allow water to flow. The olfactory organ is elongated and cup shaped possessing 65-70 lamellae radiating from the central raphae on both the sides (Fig. 1). The lamellae show sensory and nonsensory regions (Fig.4A). At the proximal end and towards the basal area of the lamellae, sensory region has cilliary receptor cells with supporting and basal cells (Fig.4A). Middle portion of the lamellae is nonsensory which is covered by the goblet cells, basal cell, epithelial cells and mast cells (Fig. 4A). These lamellae receive fascicles or fibers from its proximal end and extend into olfactory nerve (Fig. 1). Olfactory nerve is short and caudally connected to the olfactory bulb. The olfactory bulb is divisible into four layers. Outer layer is called as olfactory nerve layer (ONL) which has axons of olfactory receptor neurons (ORN's). Below ONL, axons group together, forming glomeruli, called as Glomerular layer (GL). The glomeruli innervate the bigger sized neurons called mitral cells which form the Mitral cell layer (MCL). In the centre, densely packed small cells are present forming Granular cell layer (GCL) (Fig. 1).

Fibers from the olfactory nerve penetrate peripherally in the olfactory bulb and innervate profusely forming glomerular structure on the larger sized mitral cells which show moderate Nissl's staining. The smaller cells found in GCL show light Nissl's staining. The cells are placed in dorsomedial and ventromedial position and intense Nissl's staining is observed. These are the giant cells of nucleus terminalis (NT) (Fig. 4B).

Forebrain

In *N. notopterus,* forebrain is divided into telencephalon and diencephalon.

Telencephalon: Telencephalon is divisible into two main regions i.e. area dorsalis telencephali and area ventralis telencephali. Organization of forebrain is depicted in figure- 2, 3. The area dorsalis telencephali is subdivided into pars medialis (Dm), pars centralis (Dc), pars lateralis dorsal (Dld) and pars lateralis ventral (Dlv). The neurons are rounded in shape, small in size, located near the medial region of the dorsal telencephalon (Dm) and show moderate Nissl's staining. The neurons in the area Dc are sparsely distributed and show intense Nissl's staining. The cells are smaller in size in the area Dld, rounded in shape and exhibit light Nissl's staining, while neurons in area Dlv are compactly arranged, spindle shaped, small in size and moderately stained. The area ventralis telencephali is broadly divided into pars ventralis (Vv), pars dorsalis (Vd) and pars lateralis (Vl). The cells of the Vd are bigger as compared to Vv, rounded in shape and show intense Nissl's staining. The neurons in the Vv are spindle shaped and show intense Nissl's staining. In the area Vl, rounded or oval, larger sized neurons showing moderate Nissl's staining are observed. The lateral forebrain bundles are present in ventro-lateral position of the telencephalon. Adjacent to the forebrain bundle, bigger sized multipolar neurons are seen forming a cluster

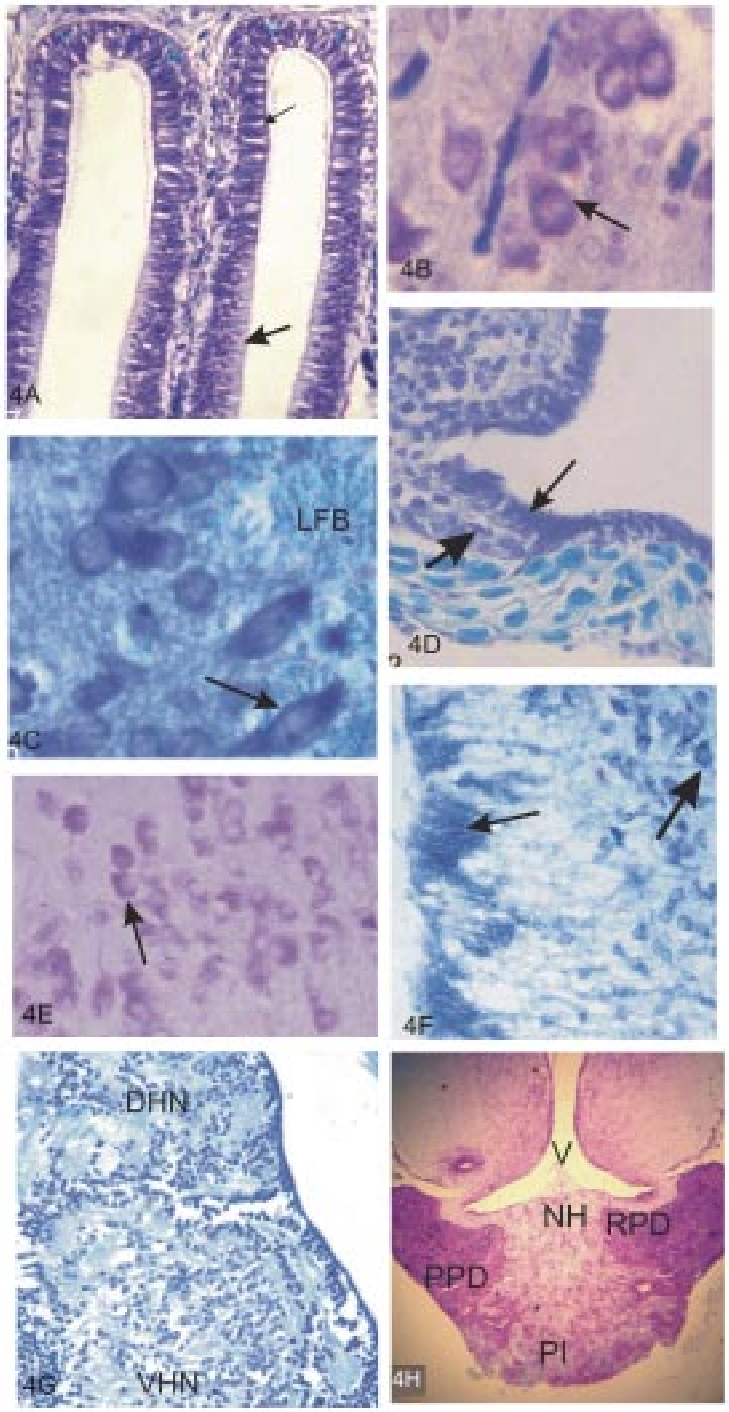

Fig. 4 A. Transverse section of the olfactory organ showing the sensory (arrow) and nonsensory (thick arrow) regions in the lamellae. Kluver and Barrera 450X.

Fig. 4 B. Sagittal section of olfactory bulb showing bigger sized intense Nissl's stained neurons of nervus terminalis (NT) (arrow). Kluver and Barrera. 400X.

Fig. 4 C. Transverse section of the brain through telencephalon showing bigger sized neurons adjacent to the lateral forebrain bundle (LFB) in the nucleus entopenducularis (NE) (arrow) with intense Nissl's staining. Kluver and Barrera. 1000X.

Fig.4 D. Transverse section of the brain through diencephalon showing nucleus of subventricular gray (thick arrow) and organum vasculosum laminae terminalis (arrow) located at the base of the preoptic recess. Kluver and Barrera. 400X.

Fig. 4 E. Transverse section of the brain through diencephalon showing moderte staining of Aldehyde Fuschin in nucleus preopticus pars magnocellularis (arrow) (NPOm). 400X.

Fig. 4 F. Transeverse section of the brain through tuberal area showing paraventricular organ (PVO) (arrow), cells of nucleus of PVO (NPVO) (thick arrow) showing intense staining of Nissl's. Kluver and Berrera. 400 X.

Fig.4 G. Transverse section of brain the through epithalamus showing habenular ganglion with dorsal habenular nucleus (DHN) and ventral habenular nucleus (VHN). Kluver and Berrera. 160 X.

Fig.4 H. Transverse section of brain the with pituitary gland. Pituitary attached to the brain below third ventricle (V). Pituitary gland showing neurohypophysis(NH), rostral pars distalis (RPD), proximal pars distalis (PPD) and pars intermedia (PI). Kluver and Berrera. 50 X.

which is nucleus entopeduncularis (NE) (Fig. 4C). It shows intense Nissl's staining (Fig. 4C). These neurons are AF- negative. Telencephalic lobes are connected with each other by anterior commissure which is located dorsal to the preoptic recess.

Diencephalon: In *N. notopterus,* diencephalon includes four regions i.e. preoptic area, hypothalamus, thalamus and epithalamus.

Preoptic area: Preoptic area of *N. notopterus* is an important region which constitutes major part of anterior diencephalon. It is the portion of prosencephalic wall covering preoptic recess of the third ventricle. Anteriorly it is covered by anterior commissure, dorsally by the telencephalon and ventrally by the optic chiasma. The preoptic area contains AF-positive and AF- negative neuronal groups. The neurons of the nucleus preoptics magnocellularis (NPOm) are AF-positive and other nuclei in the preoptic area are AF- negative. Nucleus of subventricular gray (NSG) is an unpaired group of cells situated ventral to the preoptic recess. It begins at the anterior limit of preoptic recess, and comprises of neurons of oval shape showing moderate Nissl's staining (Fig. 4D). Oraganum vasculosum laminae terminalis (OVLT) is located in ventral wall of preoptic recess and is organized by epidymal and parenchymal layers. OVLT shows many parenchymal cells sending apical processes into the third ventricle and shows intense Nissl's staining (Fig. 4D).

In the preoptic area, there is paired paraventricular neuronal complex of the preoptic recess which is AF-negative. Nucleus of anterior commissure (NAC) is one of the important nuclei of preoptic area which is AF-negative. It is located near the ventral margin of the anterior commissure and lateral side of the preoptic recess. The neurons of NAC are spindle or oval in shape and show moderate Nissl's staining. Suprachiasmatic nucleus (SCN) is an important AF-negative nucleus in the preoptic area. SCN shows rounded, compactly arranged neurons and shows moderate Nissl's staining. Nucleus preopticus periventricularis (NPP) is also AF-negative. It is located close to the preoptic recess on both the sides. NPP is divided into nucleus preopticus periventricularis dorsal (NPPd) and ventral (NPPv). Neurons of NPPd area are comparatively bigger in size, round in shape and show moderate Nissl's staining. NPPv cells are sparsely distributed, rounded and show moderate Nissl's staining.

In *N. notopterus,* neurons of NPO are present on either side of the preoptic recess. On the basis of their size, NPO neurons have been categorized into NPO pars paraventricularis (NPOp) and NPO pars magnocellularis (NPOm) on the basis of their size. The neurons of NPOp are located above the optic chiasma and around the third ventricle, NPOm neurons are larger in size as compared to those of NPOp and located dorsally around the third ventricle. Neurons of NPOp and NPOm show intense Nissl's staining. NPOp neurons are AF-negative and NPOm neurons are AF-positive and show accumulation of neurosecretory material in the cytoplasm (Fig. 4E).

Horizontal commissure (HC): HC is present in the post optic area.

Hypothalamus: Hypothalmus is made up of tuberal area and inferior lobe.

Nuclei of tuberal area: Tuberal area starts behind the horizontal commissure. These neuronal groups are located on either side of the third ventricle and its lateral recess. In this area, three important nuclei are seen adjacent to the third ventricle which are nucleus hypothalamicus ventralis (Nhv), nucleus hypothalamicus medialis (Nhm) and nucleus hypothalamicus dorsalis (Nhd). Nhv consists of sparsely distributed, rounded neurons showing moderate Nissl's staining. In Nhm, neurons present in the paraventricular position also are round in shape but show intense Nissl's staining. Above Nhv, rounded cells of Nhd are compactly arranged and show intense Nissl's staining . The nucleus lateralis tuberis (NLT) is an important nuclear group of the tuberal area located near the infundibulum. It is present on the ventral side of the horizontal commissure and extends continuously along the base of hypothalamus. On the basis of their position NLT is divided into NLT pars anterior (NLTa) and NLT pars posterior (NLTp). NLTa neurons are rounded or spindle shaped and compactly arranged showing intense Nissl's staining. NLTp neurons are rounded in shape, few in number and exhibit moderate Nissl's staining.

Paraventricular organ (PVO) is one of the important circumventricular organs, situated in the dorsal wall of the third ventricle. It begins with the pituitary gland and extends upto the region where the lateral recess joins the third ventricle. This organ consists of loosely arranged columnar cells perpendicular to the third ventricle. Two types of cells encountered in the PVO are (i) cells embedded within the ependyma called as intraependymal cells which are directly in the contact with the CSF and (ii) cells located slightly away from the ependyma called as subependymal cells that communicate by way of short processes. Both the types of cells are elongated and there are no morphological differences. PVO cells show intense Nissl's staining (Fig. 4F). Adjacent to the PVO, spindle shaped neurons are present i.e. nucleus paraventricular organ which show moderate Nissl's staining (Fig. 4F).

Caudal to the tuberal area, lateral side of the third ventricle shows lateral recesses. Around the lateral recess, compactly arranged cells of nucleus recesses lateralis (NRL) are observed. This nucleus is again sub divided on the basis of their position into nucleus recesses lateralis superior (NRLs) and nucleus recesses lateralis inferior (NRLi). NRLs consists of compactly arranged spindle shaped cells and shows intense Nissl's staining. Distribution of neurons in NRLi is sparse compared to those in NRLs. These are spindle shaped and show intense Nissl's staining.

At the level where pituitary gland terminates, two pouches of infundibular recess appear. These pouches are called mamillary recesses (MR). They have densely aggregated round shaped cells on the periphery called as nucleus mamillaris, which show moderate Nissl's staining.

Nuclear groups of inferior lobe: The nucleus inferior lobi located on the lateral side is divided into nucleus inferior lobi pars dorsalis (NILd), nucleus inferior lobi pars ventralis (NILv) and nucleus inferior lobi pars medialis (NILm). The cells of NILd are round and show intense Nissl's staining. The neurons of the NILv are spindle shaped and show moderate Nissl's staining. The neurons of NILm are rounded or spindle shaped and show weak Nissl's staining.

Thalamus: Thalamus is made up of two divisions: dorsal and ventral thalamus. In the dorsal thalamus, cells of anterior thalamic nucleus (ATN) are compactly arranged, oval and/or spindle shaped and show intense staining of Nissl's. The neurons in the posterior thalamic nucleus (PTN) are comparably less in number, sparsely distributed, spindle or rounded in shape and show moderate Nissl's staining. Ventromedial thalamic nucleus (VMN) and ventrolateral thalamic nucleus (VLN) are the parts of ventral thalamus. The neurons of the VMN are oval shaped and show intense Nissl's staining. The cells in the VLN are spindle shaped, bigger in size and show intense Nissl's staining.

Epithalamus: In the epithalamus, a pair of habenular ganglia (HG) are present dorsal to the thalamus. Both the HG are connected by habenular commissure (HbC). Each HG has two nuclei i.e. dorsal habenular nuclei (DHN), and ventral habenular nuclei (VHN). In the DHN, cells are rounded in shape, comparatively bigger in size and show intense Nissl's staining (Fig.4G). The cells in the VHN are smaller in size than DHN, spindle shaped and show intense Nissl's staining (Fig. 4G).

Pituitary gland: Pituitary of *N. notopterus* is of platybasic type. It is attached to the hypothalamus and is forward in position. The pituitary gland is divided into adenohypophysis and neurohypophysis. Axons of the hypothalamic nuclei penetrate the neurohypophysis. Adenohypophysis is subdivided into rostral pars distalis (RPD), proximal pars distalis (PPD) and pars intermedia (PI). The AF-positive cells are seen in PPD region (Fig. 4H), these cells are large in size and show accumulation of secretary material.

Discussion

In *N. notopterus,* olfactory epithelium has lamellae radiating from the raphae which show the sensory and nonsensory regions. Location of these regions varies in different species. The sensory region is at the proximal end and basal region of the lamellae in *N. notopterus*. However, in the Cyprinid *L. rohita,* sensory region is at the middle of the lamellae and nonsensory region is at the proximal and basal regions of lamellae (10), in *Rhodeus amarus*, sensory region is at base and middle of the lamellae and nonsensory region is at the proximal end (12). This suggests that even within the groups of Cyprinids such variation is observed (Undocumented data). In *N. notopterus,* olfactory bulb is of pedunculated type, connected to the telencephalon. Such type of olfactory organ is also found in other members of family Cyprinidae and Acanthidae (13). Olfactory bulb comprises of four layers from superficial to the deep in *N. notopterus.* The fibers of the olfactory receptor neurons (ORNs) extend caudally over the olfactory nerve and penetrate the bulb from anterior side and spread along the periphery of the bulb in some teleosts (10, 12, 14) which are also seen in *N. notopterus.* In the olfactory bulb of *N. notopterus,* on the ventromedial and dorsomedial side, giant cells of the nervus terminalis have been identified. Smaller cluster of the deeply stained ganglion cells along ventromedial surface of the nervus terminalis is also noted in *Ictalurus punctatus* (13). Telencephalon in *N. notopterus* consists of two hemispheres connected to each other by anterior commissure (AC) and is basically divided into area dorsalis telencephali and area ventralis telencephali. Other teleosts also exhibit the same pattern of division (3, 6, 8, 10). Area dorsalis telencephali is subdivided into Dm, Dc, Dld, Dlv according to reviews by Meek and Nieuwenhuys and Rodriguez-Gomez et al. (8, 15). In number of other teleosts, area ventralis telencephali is subdivided into Vv, Vd, Vl and NE (2, 8, 10, 15, 16) depending on the area which they occupy and same is observed in *N. notopterus.*

Diencephalon is considered to be the most complex region in the brain of the teleosts (9). It is the neuronal integration centre in the goldfish for gustatory information, reproduction and vision (17). Recently, using cytoarchitectonic criteria, epithalmus, thalamus, hypothalamus and preoptic area are included as the parts of the diencephalon in *Dicentrarchus labrax* (9, 10). This type of division of diencephalon is used in the cytoarchitectural analysis to study the organization of the neuronal groups in the brain of teleosts (2, 6, 8-10, 16, 17). In *N. notopterus*, same pattern of division is observed. Preoptic area is the part of rostralmost diencephalic subdivision (15). A dense aggregation of nuclei around the third ventricle is an important landmark to localize the preoptic area. Nucleus of subventricular gray is unpaired group of cells at the preoptic recess in *N. notopterus* which appears to be homologous to the thin subventricular strand of gray which interconnects the nuclei of two sides in sunfish, perch, darter and goldfish (18). This nucleus is also reported in reptiles (19). The organum vasculosum laminae terminalis (OVLT) is located in the ventral wall of preoptic recess and is well developed and highly vascularised in *N. notopterus.* OVLT has been reported in almost all the vertebrate classes (20) and is considered as neurohaemal organ. NPO of teleosts is known to be homologous to the supraoptic and paraventricular nuclei of the higher vertebrates; the aspect has been extensively studied and/or reviewed (21-23). NPO area has been subdivided into magnocellular, parvocellular, preoptic nucleus and suprachiasmatic nucleus (17, 23). In the present study, AF-negative small NPO cells, referred as pars parvocellularis and AF-positive large cells called as pars magnocellularis are observed as shown in some of the other teleosts (22, 24), situated at the level of third ventricle. Other workers employed AF-positive term for magnocellularis and parvocellularis cell groups. In the preoptic area, AF-negative smaller cell groups are divided into Nucleus preopticus periventricularis dorsalis (NPPd) and ventralis (NPPv) which are comparable to that of *Clarias batrachus* (4). The nucleus of anterior commissure in *N. notopterus* is important because of its association with the anterior commissure. This nucleus is also described in other fish and reptiles (4). Suprachiasmatic nucleus (SCN) in *N. notopterus* is an aggregation of small cells which is also reported in other fish, amphibians, reptiles and mammals (25). This nucleus receives retinal projections (26).

Another nuclear group, nucleus lateralis tuberis (NLT) has been extensively studied in several teleosts (4, 24). In some teleosts, NLT neurons are reported to be AF-positive (27), but in *N. notopterus* also, they are AF-negative. Functionally, the role of NLT in the control of gonadotropic cells is well documented in number of teleosts(28).

In *N. notopterus*, on the lateral side of the third ventricle, the anterior tuberal area consists of Nhm, Nhd and Nhv. The Nhm and Nhd are comparable with the nucleus periventricularis posterior of *Corydora palitus* but in other vertebrates it is described as a dorsal hypothalamic nucleus in a similar position (17, 23, 29).

In caudal part of the tuberal area, on the lateral side of the third ventrical, hypothalamus gives extensions called as the lateral recesses: lateralis superior and inferior in *N. notopterus*. In salmonids, catecholamine producing cells of nucleus recesses lateralis (NRL) and NRL in *Clarias batrachus* seem to be the similar ones (4). The nucleus paraventricular organ (NPVO) associated with paraventricular organ (PVO), shown in *Clarias batrachus* by Ramakrishna and Subhedar is comparable with the present study(4). At the caudal end of the hypothalamus, mamillary recess appears and around the recess, mamillary nucleus is observed in *N. notopterus.* Such, studies are also reported in other teleosts (2, 17, 23).

In *N. notopterus*, inferior lobe in the hypothalamus has two prominent nuclei, nucleus inferior lobi pars dorsalis (NILd), nucleus inferior lobi pars ventralis (NILv) and nucleus inferior lobi pars medalis (NILm) but earlier workers have shown only one nucleus i.e. nucleus diffuse lobi inferioris (2). Same findings are noted in *Clarias batrachus* by Ramakrishna and Subhedar (4). In *N. notopterus*, thalamus is divided into dorsal and ventral portions. In the dorsal division, there is anterior thalamic nucleus (ATN) and posterior thalamic nucleus (PTN), while in the ventral thalamus, two nuclei are identified i.e. the ventrolateral thalamic nucleus (VLN) and ventromedial thalamic nucleus (VMN), but in *Dicentrarchus labrax*, dorsal thalamus is formed by three nuclei: the ATN, PTN and the central posterior thalamic nucleus. Ventral thalamus is made up of nucleus of thalamic ementia, the VLN, VMN and the intermediate thalamic nucleus (9, 17, 23). Such type of division however, is not clearly marked in *N. notopterus*.

Epithalamus region in *N. notopterus* consists of habenular ganglia and the habenular commissure. Habenular ganglia consist of the dorsal and ventral nuclei, as reported in other teleosts (9, 15, 17).

Pituitary gland in *N. notopterus* is platybasic and is divided into adenohypophysis and neurohypophysis. Adenohypophysis is subdivided into rostral pars distalis (RPD), proximal pars distalis (PPD) and pars intermedia (PI). Similar pattern is also reported in other teleosts (30).

As teleost is a big group of fishes showing enormous diversity, it is important to uncover the underlying pattern of brain to determine the anatomical and functional correlation of its various parts. Teleosts are further unique in vertebrates, in that they show direct innervations of hypothalamic nuclei in adenohypophysis. This study will thus be helpful to find out the correlation of brain and pituitary gland in the order Osteoglossiformes.

Reference

1. Nelson JS. Fishes of the world. New York. John Wiley and Sons, Inc 2006; VI: 601.
2. Peter RE, Gill VE. A stereotaxic atlas and technique for forebrain nuclei of the goldfish, *Carrassius auratus*. J Comp Neurol 1975; 159: 69-02.
3. Bass AH. Olfactory bulb efferents in the channel catfish, *Ictalurus punctatus.* J Morph 1981; 169: 91-11.
4. Ramakrishna NS, Subhedar N. Cytoarchitectonic pattern of hypothlamus in the catfish, *Clarias batrachus* (Linn.). J Hir Forsch 1991; 32: 289-08.
5. Arevalo R, Alanso JR, Garcia-Ojeda E, et al., NADPH-diaphorase in the central nervous system of the tench (*Tinca tinca* L., 1758). J Comp Neurol 1995; 352: 398-20.
6. Riedel G. The forebrain of the blind cave fish *Astynanax hubbs* (Characidae). Brain Behav Evol 1997; 41: 20-38.
7. Ishikawa Y, Yoshimoto M, Yamamoto N, Ito H. Different Brain Morphologies from Different Genotypes in a Single Teleost Species, the Medaka *(Oryzias latipes)*. Brain Behav Evol 1999; 53: 2-9
8. Rodriguez-Gomez FJ, Rendon-Unceta MC, Sarasquete C, Munoz-Cueto JA. Localization of tyrosine hydroxylase-immunoreactivity in the brain of the Senegalese sole, *Solea senegalensis.* J Chem Neuroanat 2000; 19: 17-32.
9. Cerda-Reverter JM, Zanui S, Munoz-Cueto JA. Cytoarchitectonic study of the brain of a perciformis species, the sea bass (*Dicentrarchus labrax)*, II The diencephalon, J Morphology 2001; 247: 229-51.
10. Bhute YV, Masram SC, Raut IN, Baile VV. Cytoarchitectonic pattern of the olfactory system, forebrain and pituitary gland of the Indian major carp, *Labeo rohita.* Annals Neurosci 2007; 14: 30-36.
11. Kluver H, Barrera E. A method for the combined staining of cells and fibers in the neurons system. J Neuropathalo Exp Neurol 1953; 12: 400-03.
12. Baby SM, Ueck M, Prasada Rao PD. Gonadotropin-releasing hormone-immunoreactive neurons and associated nicotinamide adenine nucleotide phosphate-diaphorase-positive neurons in the brain of teleosts, *Rhodeus amarus.* Gen Comp Endocrinol 2000; 120: 44-54.
13. Bass AH. Telencephalic effernts in the channel catfish, *Ictalurus punctatus*: Projections to the olfactory bulb and optic tectum. Brain Behav Evol 1981b; 19:1-16.
14. Khan FA, Saha SG, Sarkar S, Subhedar N. β-endorphin-like immunoreactivity in the forebrain and pituitary of teleosts *Clarias batrachus (Linn.)* Gen Comp Endorcrinol 1999; 113: 290-01.
15. Meek J, Nieuwenhuys R. Holosteans and teleosts. In: Nieuwenhuys R, Ten Donkelaar HJ, Nicholson C (Eds.), Central Nervous System of Vertebrates, Berlin. Springer Verlag 1998; 2: 759-937.
16. Peter RE, Macey MJ, Gill VE. A stereotaxic atlas and technique for forebrain nuclei of the killifish, *Fundulus heteroclitus*. J Comp Neurol 1975; 159:103-28.
17. Braford RMJr, Northcutt RG. Organization of the diencephalon and pretectum of the rayfinned fishes. In: Davis R, Northcutt R (Eds.), Fish Neurobiology, University of Michigan Press, Ann Arbor 1983; 2: 361-68.
18. Crosby EC, Showers MJ. Comparative anatomy of the preoptic hypothalamic area. In: Haymaker W, Anderson E, Nauta, WJH (Eds.), The hypothalamus, Springfield III, Ch C Thomas 1969; 61–135.
19. Prasada Rao PD, Subhedar N, Raju PD. Cytoarchitectonic pattern of the hypothalamus in the cobra, *Naja naja*. Cell Tissue Res 1981; 217: 503-29.
20. Tsuneki K. A survey of occurrence of about seventeen circumventricular organs in brains of various vertebrates with special reference to lower groups. J Hirnforsch 1986; 27: 441-70.

21. Scharrer EA, Scharrer B. Hormones produced in neurosecretory cells. Recent progr Hormone Res 1954;10: 183-240.

22. Peter RE, Fryer JN. Endocrine functions of the hypothalamus of Actinopterygii. In: Davis R, Northcutt R Ed., Fish Neurobiology, University of Michigan Press, Ann Arbor 1983; 2:165-201.

23. Fernald R, Shelton L. The organization of the diencephalon and the pretectum in the cichlid fish, *Haplochromis burtoni*. J Comp Neurol 1985; 238: 202-17.

24. Prasada Rao PD, Betole UK. Changes in the hypothalamo-hypophysial complex after gonadectomy in the catfish, *Clarias batrachus* (Linn.). Zool Beitr 1973; 19:319-33.

25. Neary TJ, Northcutt RG. Nuclear organization of bull frog diencephalon. J Comp Neurol. 1983; 23:262-78.

26. Springer AD, Mednick AS. Selective innervations of the goldfish suprachiasmatic nucleus by ventral retinal ganglion cell axons. Brain Res 1984; 323: 293-6.

27. Haider S, Sathyanesan AG. The Nucleus lateralis tuberis of the freshwater teleost *Heteropneursts fossilis* (Bl.). Acta Anat 1972; 82: 75-84.

28. Billard R, Peter RE. Gonadotropin release after implantation of anti-estrogen in the pituitary and hypothalamus of goldfish, *Carassius auratus*. Gen Comp Endocrinol 1977; 32: 213-20.

29. Millar RN. The diencephalic cell masses of the teleosts, *Corydora paliatus*. J Comp Neurol 1940; 73: 345-78.

30. Peter RE, Yu KL, Marchant TA, Rosenblum PM. Direct neural regulation of the teleost adenohypophysis. J Exp Zool Suppl 1990; 4: 84-9.

ERRATUM

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