Endocrine Glands of Fish

The glands that secrete their products into the bloodstream and body tissues along with the central nervous system to control and regulate many kinds of body functions are known as endocrine gland. In fishes various endocrine gland has been found associated with different tasks and functions.

Endocrine glands of fishes: Different types of endocrine glands are found in fishes; such as-

- The pituitary gland or Hypophysis
- Thyroid Gland
- Adrenal gland
- Corpuscles of Stannius
- Ultimobranchial Glands
- Urohypophysis
- Pancreatic islets
- Pineal gland

The components of endocrine system can be classified on the basis of their organization, which is as follows:

(A) Discrete Endocrine Glands:

These include pituitary (hypophysis), thyroid and pineal (Fig. 19.1).

(**B) Organs containing both endocrine and exocrine functions:**

In fishes, it is kidney, gonads (Fig. 19.1) and intestine. Kidney contains heterotopic thyroid follicles, inter-renal, and corpuscles of Stannius.

(C) Scattered Cells with Endocrine Function:

They are known as diffused neuro-endocrines. They are present in digestive tract (Fig. 19.1). They are generally called as paracrines (e.g., somatostatin). There are gastrointestinal peptides whose definite classification as hormone or paracrine agent has not yet been established, these are designated as putative hormones.

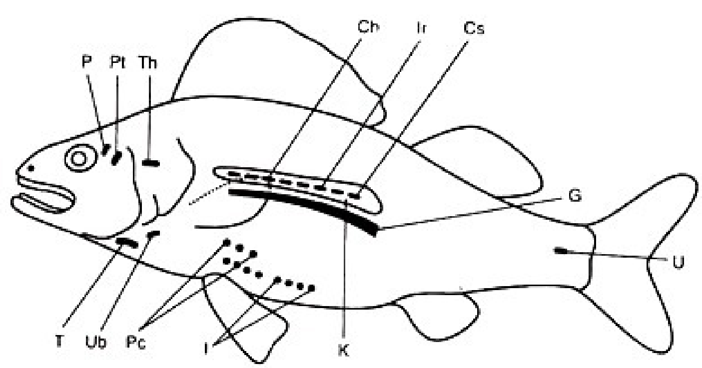

Fig. 19.1 : Schematic diagram to show position of various endocrine glands in fishes. Ch. chromaffin tissue; Cs, corpuscles of Stannius; G, gonad; I, intestinal tissue; Ir, interrenal tissue; K, kidney; P, pineal; Pc, pancreatic islets; Pt, pituitary; T, thyroid; Th, thymus; U, urohypophysis; Ub, ultimobranchial.

Chemically, hormones can be divided into three classes:
(I) Steroid hormones (testosterone & estradiol)

(II) Protein (peptide) hormones (e.g., insulin) and peptide hormones are secreted by hypophysis, thyroid, internal tissue and pancreatic tissue.

(III) The amino acid analogues are norepinephrine and epinephrine, collectively called catecholamines.

Endocrine glands of increasing complexities are found in cyclostomes, elasmobranchs and osteichthyes. Elasmobranchs (sharks) possess well developed endocrine glands but these show some interesting differences from those of higher chordates. However, osteichthyes (bony fishes) have endocrine glands rather more similar to higher chordates.

The difference between fish and mammal endocrine glands is probably due to the development and modification of various body systems in these two classes, and also due to exigencies of an aquatic mode of life.

Mammalian endocrine glands are well advance and well-studied but fish endocrinology is limited to the work on its influence on chromatophores, action of sex cells, function of pituitary and thyroid and control on migration.

Unlike nervous system, the endocrine system is basically related to comparatively slow metabolism of carbohydrate and water by adrenal cortical tissue, nitrogen metabolism by adrenal cortical tissue and thyroid glands and the maturation of sex cells and reproductive behaviour by the pituitary gland and gonadal hormones.

Pituitary Glands:

Origin of Pituitary Glands:

The pituitary gland occupies the same central part in the endocrine signalling system of fish that it has in mammals. This master endocrine gland originates embryo-logically from the two sources. One as ventral down-growth of a neural element from the diencephalon called the infundibulum to join with another, an ectodermal up-growth (extending as Rathke's pouch) from primitive buccal cavity.

These two outgrowths are thus ectodermal in origin and enclose mesoderm in between them, which later on supply blood to the pituitary gland, originating from the inter-renal carotid artery.

Location of Pituitary Glands:

The pituitary gland is located below the diencephalon (hypothalamus), behind the optic chiasma and anterior to saccus vasculosus, and is attached to the diencephalon by a stalk or infundibulum (Fig. 19.2). The stalked pituitary is found in *Barbus stigma* and *Xiphophorus maculatus*.

The size of infundibulum varies according to the species. Usually in cyclostomes it is smaller but increases in bony fishes, with prominence in groove or depression of para-sphenoid bone receiving the gland. There is no sella turcica comparable to that found in mammals in *Xiphophorus*. The short, thick- walled, hollow infundibular stalk contains a lumen, which continues with the third ventricle.

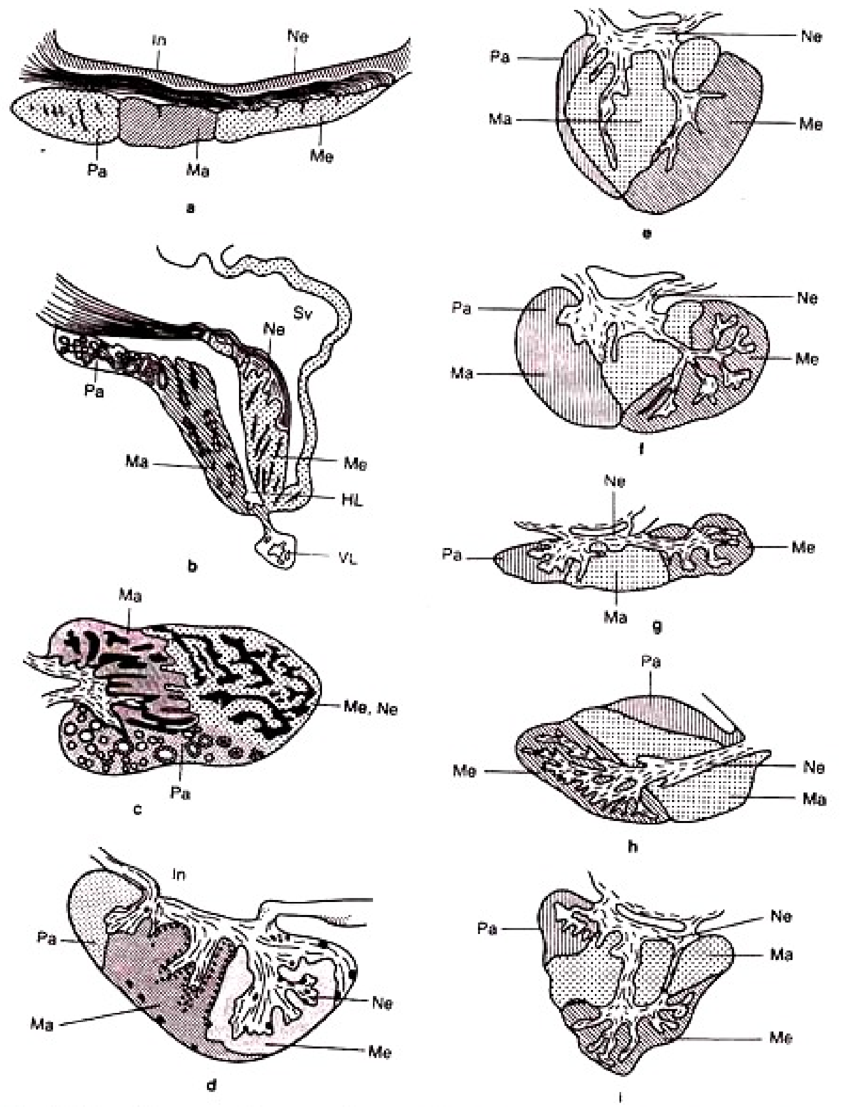

Fig. 19.2a-i : Diagrams of pituitary of various fishes. (a) *Petromyzon*. (b) Dogfish shark (*Squalus*). (c) Trout (*Salmo*). (d) Perch (*Perca*). (e) Rainbow trout. (f) Ayu (*P. altivelis*). (g) Eel. (h) Carp. (i) Yellow tail. HL, lumen of hypophysis; In, Infundibulum; Ma, mesoadenohypophysis; Me, metaadenohypophysis; Ne, neurohypophysis; Pa, proadenophypophysis; SV, saccus vasculosus; VL, ventral lobe; (Source : a-d, Pickford and AtZ, 1957; e-i, Hibiya, 1982).

Shape and Size of Pituitary Glands:

The pituitary is an oval body and is compressed dorsoventrally. The size of sexually mature platy-fish has a mean anterior posterior length of 472.9 micra, with mean width of 178 micra and mean depth of 360 micra. Male glands are smaller than those of females.

On ventral aspect the gland gradually tapers caudally from rounded anterior end. The dorsal surface of the pituitary of platy-fish is concave, ventrally it is slightly convex. The pituitary gland is completely enveloped by a delicate connective tissue capsule.

Anatomy of the Pituitary Glands:

Microscopically, the pituitary gland is composed of two parts:

(i) Adenohypophysis, which is a glandular part originated from the oral, ectoderm.

(ii) Neurohypophysis, which is a nervous part originated from the infundibular region of the brain. Both parts are present in close association.

Pickford and ATZ (1957) divided adenohypophysis into three parts, viz., pro-adenohypophysis, mesoadenohypophysis and metaadenohypophysis while Gorbman (1965) divided adenohypophysis into three parts but called them as rostral pars distalis, proximal pars distalis and pars intermedia.

However, nomenclature is synonyms as follows:

Pro-adenohypophysis – Rostral pars distalis

Mesoadenohypophysis – Proximal pars distalis

Metaadenohypophysis – Pars intermedia (Fig. 19.2).

1. Rostral Pars Distalis (Pro-Adenohypophysis):

Lying dorsal to the mesoadenohypophysis in the form of thin strip (Fig. 19.2a-i).

2. Proximal Pars Distalis (Mesoadenohypophysis):

Lying almost in between the rostral pars distalis and pars intermedia.

3. Pars Intermedia or Metaadenohypophysis, viz.:

Lying at the distal tapering end of the pituitary gland (Fig. 19.2a-i). Pituitary are broadly characterized as platybasic and leptobasic. In platybasic form (Eel), the neurohypophysis consists of flat floor of the caudal infundibulum which sends processes into disc-shaped adenohypophysis.

In leptobasic, the neurohypophysis has a fairly well developed infundibulum stalk and the adenohypophysis is globular or egg shaped. There are many intermediate between the two. Both types have similar structures described above (Fig. 19.2a-i).

I. Adenohypophysis:

Earlier workers identified cells of adenohypophysis on the basis of staining procedures. The procedures used were Heidenhain’s azon method, Masson’s poncean acid fuschin anilin blue, the periodic acid Schiff’s reaction (PAS), aldehyde fuschin technique (AF) and then they made cell counts.

The cells of pituitary secrete hormones and hormones are stored in granules present in the cytoplasm. The cells are, therefore, classified on the basis of staining properties of granules of these cells. Cell types of adenohypophysis, on the basis of staining reaction, to the mixture of acidic and basic dyes with secretory granules are called as acidophilic and basophilic.

On the basis of binding affinities with ribonucleoprotein the two classes are also classified as chromophobes and chromophils. The chromophobes have little affinity with dye while chromophils stain strongly as they have affinity with dye.

Chromophilic cells which take acidic stain are called as acidophils whereas the chromophilic cells which bound basic dye are called basophilic and the cells which do not take any stain are called chromophobes. The acidophilic cells are PAS (periodic acid Schiff) and AF (aldehyde fuschin) negative cells. The basophilic cells are AF and PAS positive.

Recently on the basis of immunocytochemistry, the cells are classified according to hormones released by the pro-adenohypophysis.

For example, the cells which take basophilic stain but produce adrenocorticotropic hormones, they are called ACTH cells but if secrete thyroid stimulating hormone, these cells are called thyrotrophs and if they secrete FSH hormones they are called gonadotrops although they are basophilic in nature.

The cells of adenohypophysis when stained with periodic and Schiff (PAS) and aldehyde fuschin methods/if do not take stain, they are PAS and AF negative.

The teleost hypo-thalamo-pituitary system is unique amongst vertebrates, as there is direct innervation of pars distalis by neurosecretory neurons of hypothalamus and there is loss of modification of the typical vertebrate hypothalamohypophysial portal vascular system for transport of neurohormones to pars distalis.

(a) Pro-Adenohypophysis:
It contains cells which secrete prolactin and corticotropin (ACTH) exclusively in addition to other hormones.

(b) Mesoadenohypophysis:
The mesoadenohypophysis (proximal pars distalis) contains cells which produce gonadotropin (GTH) and growth hormone (GH). Thyrotropin cells may occur in either or both in rostral pars distalis and proximal pars distalis. Acidophils rounded or oval or sometime pyramidal shaped.

They are coarsely granular, and give the cytoplasm a splotched appearance. They have round to oval peripheral nuclei. Basophils (cyanophilic) are spherical with large, round, centrally located nuclei. Their cytoplasm is finely granular, chromophobes cells are similar in structure as they are found in pro-adenohypophysis. The basophilic (cyanophilic) cells are PAS positive and AF positive.

(c) Metaadenohypophysis:

It also encompasses more neurohypophysial tissue than any other region. The meta-adenohypophysis basophilic cells are PAS positive. However, the granular cells do not show consistent staining reaction with PAS and AF stains.

II. Neurohypophysis:

The neurohypophysis occupies considerable portion of the gland and possesses many interesting and distinctive features. The neurohypophysis comprises connective tissue, neuroglia cells and loosely tangled network of nerve fibres.

These nerve fibres are scattered horizontally along the dorsal part of the adenohypophysis and run vertically, which are generously inter-spread with granular material, large irregularly shaped amorphous masses and large nuclei.

They are located in the mid-dorsal region. The amorphous masses are called “Herring bodies”, which have an intimate relation with the di-encephalic neuro-secretory cells called nucleus preopticus by means of a fibre tract known as the preoptic neurohypophysial tract.

The diencephalon another parts of the brain contain a group of neurons and each group is called nucleus. The NPO and NLT are important as their axons are in association with both adenohypohysis and neurohypophysis (Fig. 19.3). These possess neurosecretory cells.

The nucleus preopticus (NPO, preoptic nucleus) is situated on either side of the optic recessus slightly in front of the optic chiasma. The preoptic nucleus (NPO) is further subdivided into two parts, I, Pars parvocellularis, it is located anteroventrally and consists of relatively small cells, II, pars magnocellularis, it is situated posterodorsally and comprises relatively larger cells.

The preoptic nucleus (nucleus preopticus, NPO), their axons and nerve endings in the pituitary are stainable by neurosecretory stains. The neurons with Gormori’s chrome alum haematoxylin, aldehyde fuschin and alcian blue, can differentiate the NPO from other nuclei in preoptic region as they are neurosecretory in nature.

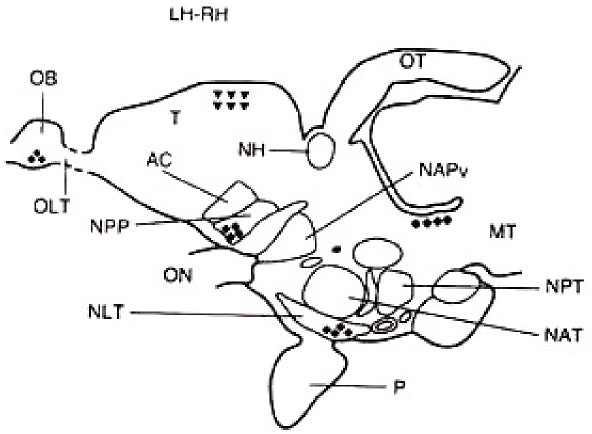

Fig. 19.3 : Diagram to show NPO and NLT in the brain of platyfish. AC, anterior commissure; MT, mid-brain tegmentum; NAT, nucleus anterioris tuberis; NAPv, nucleus anterioris periventricularis; NH, nucleus habenularis; NLT, nucleus lateral tuberis; NPO, nucleus preopticus; NPP, nucleus prepoticus periven-tricularis; NPT, nucleus posterioris tuberis; OB, olfactory bulb OLT, olfactory tract; ON, optic nerve; OT, optic tectum; P, pituitary; T, telencephalon.

Part and division of pituitary, their cell types, secretions and action of their hormones: The part of this gland their division, cell types, secretion and functions are given below in a tabular form-

Part of Pituitary	Division	Cell types	Secretions	Functions
Adenohypophysis	Proximal pars distalis	Thyrotrophs	Thyrotropins e.g TSH	Regulates the growth and secretion from thyroid
		Gonadotrophs	Gonadotropin e.g. FSH (follicular stimulating hormone) and LH (leutinizing hormone)	Regulates secretion of gonadal hormone, spermatogenesis and oogenesis
		Somatotrophs	Somatotropins e.g.GH (Growth hormone)	Increase growth and BMR of the fish body
	Rostral pars distalis	Lactotrophs	Prolactin	Regulation of osmoregulation and melanogenesis
		Corticotrophs	Corticotropin viz. ACTH	Regulates secretion of corticotropins

			from adrenal gland.
	Pars intermedia	MSH and MCH (melanophore dispersing and melanophore contracting hormone)	Regulates the concentration and dispersion of pigments within melanophores.
Neurohypophysis	Pers-nervosa	Vasopression and oxytocin	Regulates osmoregulation, salt-water balance, mating and egg laying

Blood Supply in Pituitary Glands:

Vascularization of the pituitary has been studied in variety of species. In brook trout, Salvelinus fontinalis and Atlantic salmon, Salmo salar, there is a separate blood supply to the neuro-intermediate lobe from the caudal hypothalamic artery and to the combined rostral proximal pars distalis from hypophysial arteries that branch off the anterior cerebral arteries.

According to Follenius (1963), there is no separate blood supply for rostral proximal pars distalis and pars intermedia in Salmo gairdneri but the entire blood supply originated anteriorly from the hypophysial arteries. However, in teleosts, the rostral proximal pars distalis receives blood supply from the extensive looping's of arterioles which are found near the interface with the pars distalis (Fig. 19.4).

These vessels are invaded into the pars distalis together with the interdegitations of the anterior neurohypophysis. It has been considered that these anterior loops are the rudiment of the hypothalamohypophysial portal system. However, there is no neurovascular connections with these blood vessels, as are typically found in the median eminence of various vertebrates. This hypothesis is argued as a portal system.

The function of the hypothalamohypophysial portal system as a means of transport of neurohormones to the pituitary has become redundant and pure vascular in function, probably because the pituitary cells have direct innervation by neurosecretory endings.

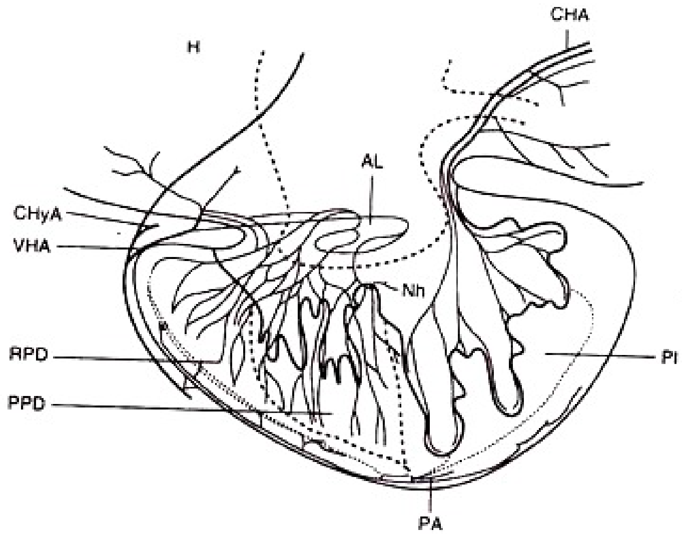

Fig. 19.4 : Para sagittal view of pituitary gland of brook trout showing blood supply. AL, arterial loops; CHA, caudal hypothalamic artery; CHyA, caudal hypophysial artery; H, hypothalamus; Nh, neurohypophysis; PA, peripheral artery; PI, pars intermedia; PPD, proximal pars distalis; RPD, rostral pars distalis; VHA, ventral hypothalamic artery.

In spite of this, a typical but small hypothalamo-hypophysial portal system has been described in variety of teleosts. According to Sathyanesan and colleagues, the branches of hypothalamic arteries form **"primary capillary plexus"** located in the meningeal tissue and the adjacent neural tissue of hypothalamus anterior to the pituitary stalk.

This plexus converges into vessels that enter the pituitary or proximal pars distalis or pars intermedia.

Thus in teleosts this portal system is the only and primary source of blood for the pars distalis. It has been considered that among teleosts the Cypriniformes or Siluriformes have reduced portal system. It is clear, however, that teleosts have neurohormones secreted more or less directly to the pituitary, and that some have the potential for vascular transportation of neurohormones by a portal system as well.

Hormones of Pituitary Glands:

There are (seven) various hormones secreted by pituitary but it is generally agreed that one cell type-one hormone concept, is correct. The different hormones secreting cell are not localized in specific region but are spread over in part of the adenohypophysis (Fig. 19.5).

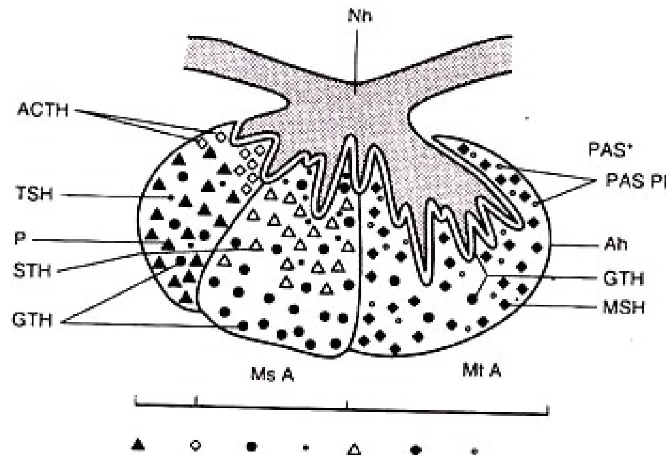

Fig. 19.5 : Section of the pituitary to show various hormone secreting cells in the adenohypophysis (Ah). ACTH, adeno corticotropic cell; GTH, gonado tropic cell; MsA, mesoadenohypophysis MtA, metaadenohypophysis; MSH melanotropic cell; Nh, neurohypophysis; PAS, periodic acid Schiff-positive cell in pars intermediate; P prolactin producing cell; STH, somatotropic cell; TSH; thyrotropic cell.

All hormones secreted by the pituitary are necessarily proteins or polypeptides. There exists a slight difference in the pituitary hormones of the different groups of fishes. The pituitary hormones of fishes are of two types (I) one which regulates the function of other endocrine glands. Such hormones are called tropins or tropic hormones.

These are:

1. Thyrotropin activates thyroid.
2. Adrenocorticotropic hormones activate adrenal cortex.
3. The gonadotropin FSH and LH (Leuteotropins, various steroid hormones).
4. Growth hormones, somatotropin (actually they are not tropic).

Hormones which directly regulate the specific enzymatic reactions in the various body cells or tissues are melanin hormones (MH) and melanophore stimulating hormone (MSH), etc. Thyrotropin hormone is secreted from pro-adenohypophysis (rostral pars distalis) and stimulate activity of thyroid hormones.

The TSH is secreted under the influence of (TRH), thyroid- releasing hormones from diencephalon in fishes. It is proved that TRH influences the TSH cell activity and thyroid activity in fish. In Carassus auratus, crude extract of the hypothalamus or goldfish results decreased radioiodine uptake by the thyroid, which indicates the presence of TRH activity in hypothalamus.

In teleosts, the TSH cells have direct innervation by neurosecretory endings, which are adjacent to the cells having no synaptic contact or the endings and may be separated from the TSH cells by a basement membrane. In *Tilapia mossambica* and *Carassius auratus* the TSH cells have direct contact with endings containing elementary neurosecretory granules, and with endings containing vesicles having dense granules.

Gonadotropin:

Gonadotropin (GTH) cells are richly found in the proximal pars distalis (PPD), where they may form a solid ventral rim of cells. Such situation is found in Cyprinoide. In salmonids and eel they are spread throughout rostral pars distalis (RPD) and PPD.

Gonadotrops are basophilic cell types and are PAS and AB positive. These cells have irregular and more or less dilated cisternae of granulated endoplasmic reticulum (GER) containing granules with varying electron density.

The gonadotroph (GTH) is under the control of gonadotropin releasing hormone. In many teleosts, unlike mammals, neurosecretory stimuli may pass along the nerve fibres piercing the laminae, that separates the neuro from adenohypophysis, and penetrating into the endocrine parenchyma of pars distalis (Ball, 1981). There are two types of nerve fibres designated as A and B types.

The fibres of A type remain in contact with hormone producing cells, including gonadotrops and even terminate with synapse on these cells. B type fibres form synaptic contact with a large granular vesicle of 60-100 nm diameter, while the A synapse have granules of 100-200 nm diameter.

The gonadotropin (GTH) releasing hormone (GnRH) of teleost is similar to luteinizing hormone releasing hormone (LH-RH) is localized in ventral lateral nucleus preopticus periventricularis (NPP) and posterior lateral nucleus lateral tuberis (NLT) as well as other areas.

In hypothalamus, localization of immunoreactive fibre tracts from cells in the NPP and NLP to the pituitary gland suggests that these areas are the origin of endogenous releasing hormone.

Studies of Peter and Crim (1978) on *Carassius auratus* indicate that the nucleus lateralis tuberis (NLT) pars posterior and the NLT pars anterior which are situated in the pituitary stalk, are actively take part in regulation of GTH secretion for gonadal recrudescence (Fig. 19.6).

In several fishes GTH secretion is associated with ovulation. In *Carassius auratus*, GTH level becomes higher on the day of ovulation. However, in sockeye salmon, *Oncorhynchus nerka*, high level of GTH found during spawning.

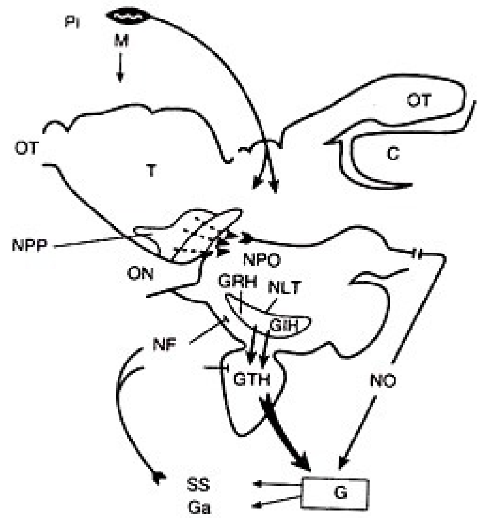

Fig. 19.6 : Diagrammatic representation of the neuroendocrine regulation of gonadotropin (GTH) secretion by releasing hormone (GRH) and one inhibitory hormone (GIH) in gold fish brain. C, cerebellum; G; gonad; Ga, gametes; M, melatonin; NF, negative feedback; NLT, nucleus lateralis tuberis; NPP, nucleus preopticus periventricularis, NPO, nucleus preopticus; NO, neural output; ON, optic nerve; OT, olfactory tract; PI, photoperiod input; SS, sex steroid; T, telencephalon. (Source; Peer and Fryer, 1983).

In fishes there is only one functional gonadotropin is found, which is often regarded as piscian pituitary gonadotropin (PPG). This single gonadotropin has similar properties of two hormones. LH and FSH of mammals. Mammalian luteinizing hormone (LH) promotes release of gametes from nearly mature gonads in fishes and stimulates appearance of secondary sexual characters.

This indicates that there must be a similar hormone in fishes also. Salmon pituitary secretes gonadotropins which resembles LH. Furthermore, the gonadotropins from human chorion and urine of gravid mares, have LH like properties which hasten the release of eggs in female fishes.

The presence of follicle stimulating hormone in fishes (FSH), which is the second gonadotropin hormone found in mammalian pituitary gland, is still not confirmed. Recently, prostaglandin, which is hormone-like substance has been isolated from testis and semen of blue fin tuna (*Thynnus thynnus)* and flounder (*Paralichthys olivaceus*).

Adrenocorticotropic Hormone (ACTH):

It is secreted by ACTH cells located between the rostral pars distalis and the neurohypophysis. Secretion of ACTH from pituitary is stimulated by the hypothalamus through corticotrophin releasing factor (CRF) (Fig. 19.7).

Hypothalamic and telencephalic extracts of *Carassius auratus* and longnose suckers, *Catostomus catostomus* stimulated secretion of ACTH in *Carassius auratus* in vivo. The nature of this telencephalic hypothalamic CRF is unknown. However, it shows similarity with mammalian CRF.

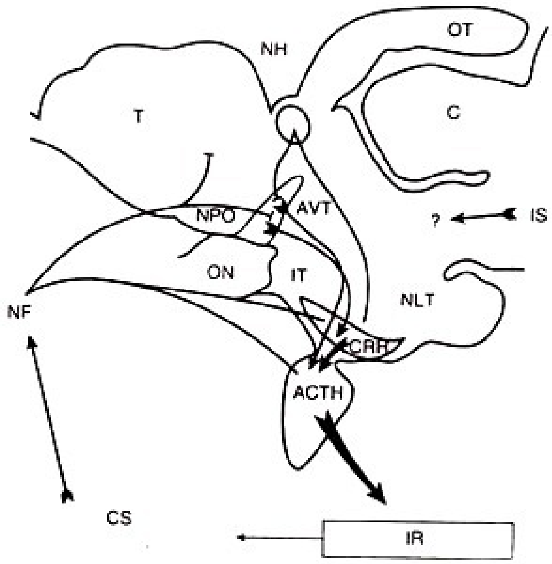

Fig. 19.7 : Diagrammatic illustration of neuroendocrine regulation of (ACTH) by a releasing hormone (RH) and (NPO)→ arrow indicates stimulatory influences; Question (?) indicates unknown pathways. AVT, arginine vasotocin; IT, isotonin; IR, inter renal; IS, input of stress; C, cerebellum; CS, cortico steroid; NF, negative feed back; NH, nucleus habenularis, NLT, nucleus lateralis tuberis; NPO, nucleus preopticus; ON, optic nerve; T, telencephalon.

In *Carassius auratus*, ACTH cells are innervated by aminergic like type B fibres, which originate from nucleus lateralis tuberis (NLT). In teleosts, neurohypophysial peptides may regulate the ACTH secretion.

Implantation of cortisol pellets in *Carassius auratus* shows that corticosteroids exert negative feedback effects on the brain to suppress ACTH secretion. Cortisol added to the medium inhibits the activity of ACTH cells and release of ACTH which also suggest direct negative feedback effect of Cortisol on the ACTH cells.

Prolactin:

It is a similar hormone that influences lactation in mammals and is released from pro-adenohypophysis. In some fishes like mummichog (*Fundulus heteroclitus*), prolactin along with the intermedin enhances the laying down of melanin in the melanophores of the skin.

Among the several hormones the prolactin is also involved in electrolytic regulation in teleosts but its importance in maintaining homeostasis varies according to species. The secretion of prolactin from the teleost pituitary is under an inhibitory neuroendocrine control of hypothalamic origin.

Growth Hormone (GH):
Mesoadenohypophysis secretes a growth hormone which accelerates increase in the body length of fishes. Very little is known concerning its control, mode of action on cell division and protein synthesis in teleosts. It has been reported that teleost GH cells are capable of some spontaneous activity and continue to synthesize and secrete GH in vitro.

It is evident that the GH secretion may be influenced by osmotic pressure, as release of GH from cultured *Salmo gairdneri* and *Anguilla Anguilla* pituitaries greater in a medium containing low sodium than in a high sodium medium, relative to plasma sodium levels. However, GH release from *Poecilia latipinna* pituitary has no effect of osmotic pressure.

Recently a zone of the hypothalamus has been recognized, which is believed to be responsible for control of GH in *Carassius auratus*. In this fish nucleus anterior tuberis (NAT) and sometimes nucleus lateralis tuberis (NLT) forms an area which stimulates GH secretion and is perhaps the origin of a growth hormone releasing hormone (GRH).

The hypothalamic control of GH secretion is revealed by ultra-structural studies on the pituitary. In teleosts GH cells of pars distalis have direct synaptoid contact with type B endings as in *Carassius auratus*, which have direct contact without the synaptoid appearance in *Tilapia mossambica*.

Very few species like *Oryzias latipes* contain synaptoid contact of type A endings on GH cells; in other teleosts, type A fibre may have direct contact with GH cells, but generally the endings are separated from the cells by a basement membrane. Thus it is clear that on neuroendocrine factor reaching the GH cells and probably the GH cells are regulated by a dual hormone.

Melanocyte Stimulating Hormone (MSH) or Intermedin:
MSH is secreted from the meta-adenohypophysis and acts antagonistically to melanin hormone (MAH). MSH expands the pigment in the chromatophores, thus takes part in adjustment of background. It also stimulates the melanin synthesis. Pars intermedia of teleost pituitary comprise two kinds of secretory cells, which can be identified by their staining properties.

One cell type is PAS^{+ve} periodic acid Schiff positive and PbH^{-ve} (lead hematoxylin negative). However second cell type is PbH^{+ve} and PAS^{-ve} (Holmes and Ball, 1974). Salmonid seems to have only PbH^{+ve} cells.
These cells are source of melanocyte stimulating hormone (MSH) which stimulates melanin despersion in the melanocytes and darkening of skin. Neuro-intermediate lobe of *Salmo gairdneri* appears to have a melanin concentrating factor.

Several authors have demonstrated the occurrence of MSH and/or its precursor ACTH in PbH cells of several species of teleosts by immuno fluorescence techniques. Thus these observations confirm earlier correlations of body colour or background adaptation with activity of the PbH cells.

In teleosts, the neuroendocrine control of pars intermedia varies according to species. In fishes like Cymatogastes aggregate, *Anguilla Anguilla* and *Salmo gairdneri*, neurosecretory axons do not enter the pars intermedia but terminate in extravascular channels bordering the pars intermedia or terminate at the basement membrane.

However, other teleosts such as *Carassius auratus*, and *Gillichthys mirabilis* have direct innervation from neurosecretory axons.

Secretion of MSH in teleost may be suppressed by catechol aminergic mechanism. Treatment of 6 OHDA to destroy catechol aminergic nerve terminals also causes activation of the MSH cells in *Gillichthys mirabilis*, darkening of skin or activation of MSH cells in *Anguilla anguilla*, catecholamine inhibits the release of MSH directly, when the former is MIH.

Also the catecholamine may affect MSH secretion indirectly by promoting the release of an MIH, or by inhibiting the secretion of an MRH nerve terminals within the pars intermedia.

Several histological investigations demonstrate a stimulation of the pars intermedia associated with reproduction. During spawning period pars intermedia of clupea becomes intensely active. In *Carassius auratus* the number of PbH^{+ve} cells increases after spawning in both number and activity during oogenesis and breeding season.

Oxytocoin and Vasopressin Hormones:
In fishes the neurohypophysis secretes two hormones, i.e., oxytocin and vasopressin, which are stored in hypothalmic neurosecretory cells. These endocrine substances have well known effect on mammalian metabolism.

Vasopressin and antidiuretic (ADH) hormones are responsible for the constriction of blood vessels in mammals and thus stimulates retention of water by their action in kidney. Oxytocin stimulates mammalian uterine muscles and increases the discharge of milk from lactating mammals.

The fish pituitary hormones are capable to produce such effects in higher vertebrates but presumably the target organs are specific site of their action in fishes and probably is different from those of higher vertebrates. In fishes they control osmoregulation by maintaining water and salt balance.

Use of pituitary hormones in induced breeding:
The pituitary hormones have practical applications by injecting and implanting to force or stimulate spawning of certain fishes of great economic value, such as trouts (Salmoninae),

catfishes (Ictaluridae), Mullets (Mugliliade), and sturgeons (Acipenseridae). The synthesis of sex hormones in the gonad is controlled by pituitary gonadotropin.

Hence pituitary extract containing GTH are taken from sexually mature male or female fish than injected to the same species for inducing and hastening and spawning. For the preparation of pituitary extract closely related species may also be used as donor.

Thyroid Gland of Fishes:

Location of Thyroid Gland:

In many teleosts the thyroid gland is situated in the pharyngeal region in between the dorsal basibranchial cartilages and ventral sternohyoid muscle. The thyroid surrounds anterior and middle parts of first, second and sometimes third afferent branchial arteries of ventral aorta, as found in Ophiocephalus species (Fig. 19.8).

In *Heteropneustes* it occupies almost the entire length of the ventral aorta and afferent arteries. In *Clarias batrachus* the thyroid gland is concentrated around the ventral aorta, middle ends of two pairs of afferent arteries and the paired inferior jugular veins.

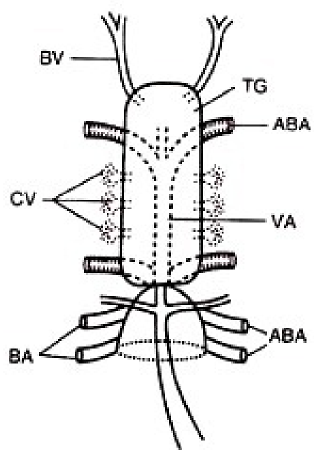

Fig. 19.8 : Ventral view of thyroid gland and their blood vessels in *Heteropneustes*. ABA, afferent branchial artery; BA, branchial vessel; BV, buccal vein; CV, commissural vessel; TG, thyroid gland; VA, ventral aorta.

Shape and Size of Thyroid Gland:

In majority of teleosts the thyroid is un-encapsulated and thin follicles are dispersed or arranged in clusters around the base of afferent branchial arteries.

It is thin-walled, sac-like, compact dark brownish and enclosed in a thin-walled capsule of connective tissue in these fishes might be correlated with the air breathing habit because thyroid gland acts here as thermoregulatory to adapt the fish to a semiterrestrial environment of low thermal capacity.

In *Heteropneustes* the thyroid gland is an unpaired thin- walled brownish but cylindrical in shape. In *Clarias batrachus* the thyroid gland is not covered by definite wall, i.e., un-capsulated and is elongated in shape.

Histology of the Thyroid Gland:

In teleosts, histologically the thyroid gland consists of a large number of follicles, lymph sinuses, venules and connective tissues. The follicles are round, oval and irregular in shape. Each follicle contains a central cavity surrounded by a wall composed of single layer of epithelial cells. The structure of epithelium varies according to its secretory activity. Less active follicles generally have thin epithelium.

Epithelial cells are of two types:

(i) Chief cells which are columnar or cuboidal in shape, having oval nuclei and clear cytoplasm.

(ii) Colloid cells or Benstay's cells. They possess droplets of secretory material. The follicles are supported in position by connective tissue fibres, which surrounds them. The central lumen of follicle is filled with colloid containing chromophilic and chromo phobic vacuoles.

Blood Supply in Thyroid Gland:

The thyroid gland is highly vascularized and is generally well supplied with blood. A single buccal vein and two pairs of commissural vessels supply blood to thyroid gland. From its posterior end a pair of veins arise, which merge immediately to form the posterior inferior jugular vein sending blood to the heart.

In *Ophiocephalus*, the thyroid gland also receives blood from same vessels. The buccal vein collects blood from the buccal region and after running for a short distance beneath the anterior end of pairs of the thyroid gland opens into it.

The two commissural blood vessels are highly branched and bring blood from the floor of pharynx. One pair opens at the anterior end while the other at the middle of the gland on either side. In *Heteropneustes* the commissural vessels are more than two pairs.

Hormones of Thyroid Gland:

Thyroid hormone is synthesized in the thyroid gland, for which inorganic iodine is extracted from the blood. These inorganic iodine combines with tyrosine. The thyroid hormones of fishes appear to be identical with those of mammals, including, mono- and di-iodo-tyrosine and thyroxin.

These hormones are kept stored in the thyroid follicles and are released into blood stream on metabolic demands. The release of the thyroid hormone from the follicle is controlled by the thyrotropic hormone (TSH) of pituitary which in turn is influenced by genetically determined maturation process along with certain factors like temperature, photoperiod and salinity. The thyroid glands in sharks and higher teleosts are diffused in nature.

Therefore, it is difficult to remove or inactivate. In spite of the certain deficiency, studies have been made by physiological blocking or radio-thyroidectomy using. In teleosts, there is no respiratory stimulation by thyroxin, which is best known in mammals. Physiologically used small quantity of thyroxin and tri-iodo-thyroxine result in thickening of the epidermis and fading of goldfish (*Carassius auratus*).

Induced thyroid hyperactivity accelerates the transformation into juvenile smolt stage in salmon but high thyroid the titer retards growth of the larva in the same genus. Induced thyroid hyperactivity in mud skipper (*Periophthelamus*) shows morphological and metabolical changes in response to the more terrestrial existence of fish living mostly outside the water. Thyroid gland of salmons and sticklebacks is known to influence osmoregulation.

In salmon the thyroid gland becomes hyperactive during their spawning migration. It has been considered that thyroid influences the growth and nitrogen metabolism in goldfish, as indicated by high ammonia excreted by them. Thus the action of thyroid is conjugated with other vital processes including growth and maturation and also the diadromous migration of fishes.

Adrenal Cortical Tissue or Inter-Renal Tissue:

Location:

In Lamprey (Cyclostomata) the endocrine inter-renal cells are present throughout the body cavity close to the post-cardinal vein. Among the rays they lie in more or less close association with posterior kidney tissue, including some species possessing inter-renal tissue concentrated near the left and in other near the right central border of that organ.

In sharks (Squaliformes) they are present between the kidneys. In teleosts the inter-renal cells are multilayered and situated along the post-cardinal veins as they enter the head kidney (Fig. 19.9).

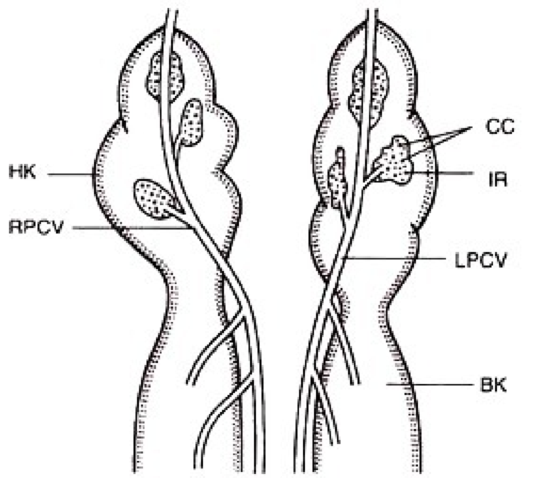

Fig. 19.9 : Digram to show location of interrenal glands in fishes. BK, body kidney, CC, chromaffin cells; HK, head kidney; IR, interrenal tissue; LPCV, left post cardinal view; RPCV, right post cardinal vein. (Source : Habia, T., 1982).

Anatomy:

In some fishes like *Puntius ticto* inter-renal cells are arranged in form of thick glandular mass while in others like *Channa punctatus* they are present in form of lobules. Each inter-renal cells is eosinophilic and columnar with a round nucleus.

Adrenal Cortical Hormone:

Adrenal cortical tissue or inter-renal tissue secretes two hormones. These are (i) mineral corticoids concerned with fish osmoregulation, (ii) glucocorticoids, which regulate the carbohydrate metabolism, particularly blood sugar level.

Salmo gairdneri treated with mineral corticoid excretes higher than normal amount of sodium ions through its gills but conserve more than normal amount of sodium in the kidneys and osmoregulation in the body.

Intramuscular injection of corticosteroid compounds to the oyster toadfish causes increase in blood sugar level thus showing control on carbohydrate metabolism. The cortisone level of blood plasma of salmons rises during spawning period and declines during the more sedentary stages.

During the spawning phases 60% of total body protein is catabolized in *Oncorhynchus*, which is correlated with the six fold increase in plasma corticosteroids and rises in liver glycogen.

Like higher vertebrates administration of adrenal cortical hormones stimulates lymphocyte release in *Astyanax* and antibody release in European perch. Corticosteroids structurally similar to androgens and produce androgens side effects. Secretion of adrenocortical hormones is under control of the adrenocorticotropic hormone (ACTH) of hypophysis.

Chromaffin Tissue or Suprarenal Bodies or Medullary Tissue:

In lamprey (Cyclostomata) the chromaffin cells are present in the form of strands along the dorsal aorta as in the ventricle and the portal vein heart. In sharks and rays (Elasmobranchii) these tissues are found associated with the sympathetic chain of nerve ganglia while in bony fishes (Actinopterygii) the chromaffin cells have wide variation in their distribution.

They are elasmobranch like, distributed as in flounders (*Pleuronectus*). On the other hand they have true adrenal arrangement as in sculpins (*Cottus*) where chromaffin and adrenal cortical tissue are joined into one organ, similar to the mammalian adrenal gland (Figs. 19.10a, b, c, d).

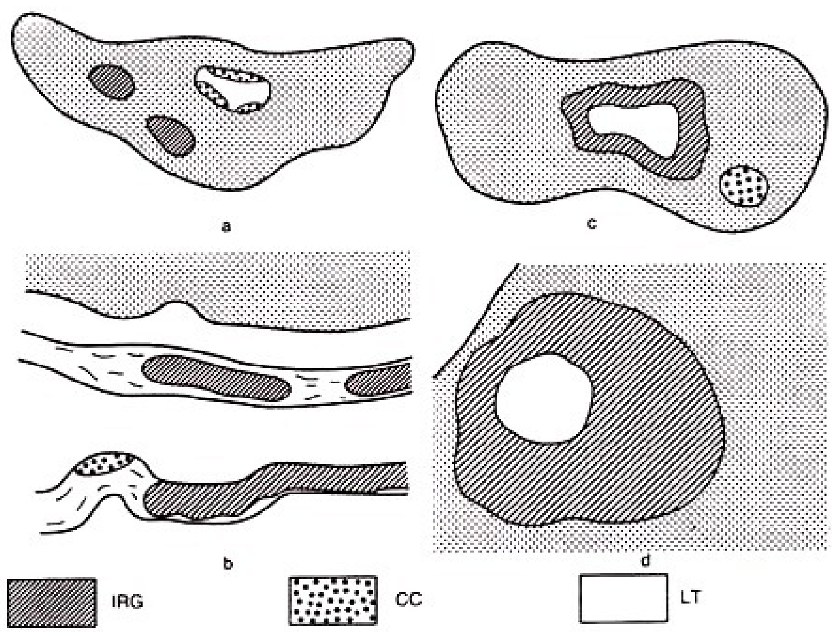

Fig. 19.10a-d : Diagram showing chromaffin tissue in fishes (a) Rainbow trout. (b) Eel. (c) Carp. (d) Yellow tail. IRG, interrenal gland; CC, chromaffin cell; LT, lymphoid tissue. (Source : Hibiya, T., 1982)

Chromaffin tissue of fishes richly contain adrenaline and noradrenaline. Injection of adrenaline and noradrenaline causes changes in blood pressure, bradycardia, branchial vasodilation, diuresis in glomerular teleosts and hyperventilation.

The Ultimo-Branchial Gland:

Typically the gland is small and paired and is situated in the transverse septum between the abdominal cavity and sinus venosus just ventral to the oesophagus or near the thyroid gland. Embryonically the gland develops from pharyngeal epithelium near the fifth gill arch. In *Heteropneustes*, the gland measures 0.4 x 1.5 mm in diameter in average adult of 130 to 150 mm body length.

Histologically, it consists of parenchyma, which is solid and composed of cell cords and clumps of polygonal cells covered by capillary network. The gland secretes the hormone calcitonin which regulates calcium metabolism.

Calcitonin is said to be related with the osmoregulation. Eel calcitonin causes decrease serum osmolarity, sodium and chloride in Japanese eels. The ultimo-branchial gland is under the control of pituitary gland.

The Sex Glands as Endocrine Organs:
The sex hormones are synthesized and secreted by specialized cells of the ovaries and testis. The release of sex hormones is under the control of mesoadenohypophysis of pituitary. In fishes these sex hormones are necessary for maturation of gametes and in addition secondary sex characteristics such as breeding tubercles, colouration and the maturation of gonopodia.

In elasmobranch (*Raja*) and in salmon the blood plasma contains male hormone testosterone with a correlation between plasma level and the reproductive cycle. *Oryzias latipes* (medaka) and sockey salmon comprise another gonadal steroid, i.e., 11-ketotestosteron, which is 10 fold more physiologically androgenic than testosterone.

Ovary secretes estrogens of which estradiol-17B has been identified in many species in addition of presence of estrone and estriol. In some fishes progesteron is also found but without hormonal function.

There is little information about the influence of gonadial hormones on the reproductive behaviour of fish. Injection of mammalian testosterone and estrone to lamprey causes development of its cloacal lips and coelomic pores, which contribute in reproductive process.

Such tests conducted for rays and sharks (Elasmobranchii) could not give any results whereas ethynil testosterone (pregnenolone) which produces mild androgenic and progesteron like effects in mammals and birds, found to be highly androgenic in fishes.

Male sex hormones are more similar to those of vertebrates than the ovarian hormones, the former strongly influences ovarian development in a loach, the Japanese weather-fish.

Corpuscles of Stannius:
The corpuscles of Stannius were first described by Stannius in 1939 as discrete gland like bodies in the kidney of sturgeon. The corpuscles of Stannius (CS) are found attached or lodged in the kidneys of fishes particularly holostean and teleost (Fig. 19.11).

Corpuscles of Stannius are asymmetrically distributed and often resembles with cysts of parasites but lie different from the latter by higher vascular supply and dull white or pink colour. Histologically, they are similar to the adrenal cortical cells. Their number varies from two to six according to species.

The CS. may be flat, oval as in goldfish, trout, salmon. It is made up of columnar cells which are covered by a fibrous capsule. The columnar cells are of two types (i) AF-positive and (ii) AF negative. They are filled with secretory granules. The parenchyma of CS comprises vasculo-ganglionic units consisting of a bunch of ganglion cells, blood vessels and nerve fibres.

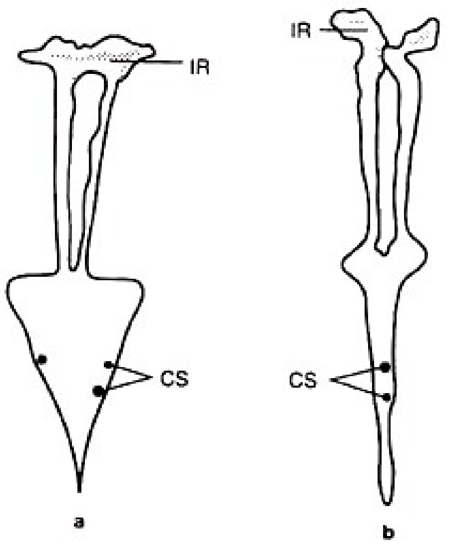

Fig. 19.11a, b : Diagram of kidney of fishes showing corpuscles of Stannius. (a) *Cirrhina mrigala*. (b) *Labeo rohita*. CS, corpuscles of Stannius; IR, interrenal corpuscles.

The number and position of CS vary in different species. Their may be single CS as in *Heteropneustes setani* and *Notopterus notopterus* (Fig. 19.11a, b), while as many as ten CS are present in some species like *Clarias batrachus*. In other species their number varies from one to four. According to Garrett (1942), there is a gradual reduction in number of CS that has occurred during evolution of Holostei and Teleostei.

In salmonids the CS is located near the middle part of mesonephros but in majority of fishes they are situated at the posterior end of kidney. Garrett (1942) pointed out that CS moves progressively backward during the course of evolution as a result of body cavity rather than a migration of CS.

In *Notopterus notopterus* the CS are present in anterior end of kidney perhaps because most of the body cavity is occupied by the air bladder and also other organs are compactly arranged in limited space.

The presence of the CS at the extreme anterior end of the kidney in *Heteropneustes setani* is probably because this species has wide body space and long archinephric duct.

Therefore, the variation in number and position of CS in teleost species seems to be an embryological speciality.

There is only one-cell type present in the CS of pink salmon. However, two-cell types are found in pacific salmon. The corpuscles of Stannius reduces serum level in the *Fundulus heteroclitus*, which have environment containing high calcium, such as sea water.

Recently, it has been shown that corpuscles of Stannius work in association with pituitary gland, which exerts hypercalcemic effect, in order to balance relatively constant level of serum calcium.

Intestinal Mucosa:
The intestinal mucosa produces secretin and pancreozymin, which are controlled by nervous system and regulate pancreatic secretion. Secretin affects flow of enzyme carrying liquids from the pancreas, whereas pancreozymin accelerates flow of zymogens.

These hormones are usually synthesized in anterior part of the small intestine. In carnivorous fish these hormones are brought into the stomach, containing acidified homogenate of fish flesh or by injection of secretin into gastric vein which stimulates the secretion of pancreas.

Islets of Langerhans:
In some fishes like *Labeo*, *Cirrhinus*, and *Channa* small islets are present which are separate from pancreas and are found near gall bladder, spleen, pyloric caeca or intestine. Such islets are often referred to as principal islets. But in some species like *Clarias batrachus* and *Heteropneustes fossilis* the number of large and small islets are found to be embedded in the pancreatic tissues, similar to the higher vertebrates.

In fish the islets are big and prominent and consist of three kinds of cells (Fig. 19.12a, b):
(i) The beta cells which secrete insulin and take aldehyde fuschin stain,

(ii) Another type of cells are alpha cells, which do not take aldehyde fuschin stain and have two types, A_1 and A_2 cells, which produce glucagon. The function of the third type of cells is not known. Insulin is secreted by beta cells and regulates the blood sugar level in fishes.

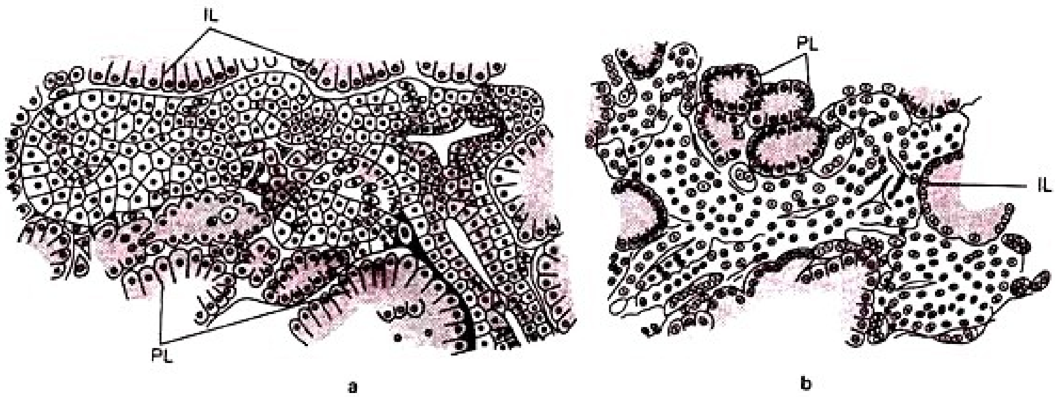

Fig. 19.12a, b : Diagram of pancreas showing endocrine components. (a) *Torpedo marmorata.* (b) *Mustelus laevis.* IL, islets of langerhans; PL, pancreatic lobule.

Pineal Organ:

It is situated near the pituitary. In-spite of being a photoreceptor organ the pineal organ shows endocrine nature of doubtful function. Removal of pineal from *Lebistes* species causes reduced growth rate, anomalies in the skeleton, pituitary, thyroid and corpuscles of Stannius. It has been reported that thyroid and pituitary glands influence the secretion of pineal.

Urophysis:

Urophysis is a small oval body, present in the terminal part of spinal cord (Fig. 19.13a, b, c). It is an organ deposits, which releases materials produced in the neurosecretory cells situated in the spinal cord.

These cells together with the urophysis are called the caudal neurosecretory system. This neurosecretory system is found only in elasmobranchs and teleosts but it corresponds to the hypo- thalamo neurosecretory system present in vertebrates.

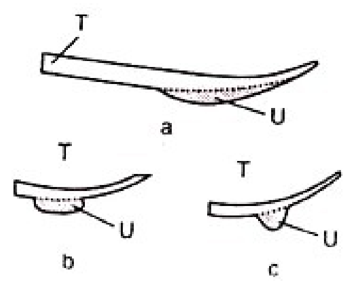

Fig. 19.13a-c : Diagram of urohypophysis of teleosts. (a) rainbow trout. (b) carp. (c) Yellow tail. T, tail; U, urohypophysis (Source : Hibiye, T., 1982)

In caudal neurosecretory system, neurosecretory cells are diffused in terminal part of spinal cord. Axon terminals of these cells assemble at the ventral side of the region and form urophysis with blood capillaries. The neurosecretory cell is a large nerve cell and has basophilic cytoplasm and a polymorphic nucleus.

In Ayu (*P. altivelis*) the urophysis is extended like a bow. In carp and yellow tail it is a conspicuous oval body. The urophysis is made up of spinal cord elements like neurosecretory axon, glia, and ependymal and glia fibers and meningeal derivative such as vascular reticulum and reticular fibres.

The caudal neurosecretory system is said to be related with osmoregulation. Urophysis extract shows ability to contract smooth muscles of ovary and oviduct of guppy (*Poecilia reticulata*) and the sperm duct of goby (*Gillichthys mirabilis*), suggesting the possibility of involvement in reproduction and spawning.

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