# Fish Endocrinology

## A. J. MATTY

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# INTRODUCTION

Endocrinology originally developed as a part of medical science and this century has seen a spectacular growth and flowering of this branch of science, just as has been witnessed in other branches of medical science. To continue the metaphor further, as the main medical branch of endocrinology grew, side-branches began to appear concerned with the behaviour of hormones in non-mammalian animals. In 1912 Gudernatsch fed pieces of horse thyroid to young tadpoles and observed them metamorphose precociously into frogs, while in 1922 Kopec postulated that the brain hormone was responsible for moulting in the moth, *Lymantria*. However, it was not until 1928 that a hormone in an invertebrate was shown to cause the contraction of the chromatophores of a shrimp and that this hormone was produced in the eye-stalk of the animals. From this period, and particularly after the discovery of moulting hormones in insects, invertebrate endocrinology developed into a separate and distinct area of endocrinology which has been well reviewed in a text by K.G. Highnam and L. Hill, *Comparative Endocrinology of the Invertebrates* (Edward Arnold, London, 1969).

Vertebrate endocrinology continued to be linked to medical physiology. Swale Vincent wrote a text entitled *Internal Secretion and the Ductless Glands* in 1924 which contained considerable information on the ductless glands of fish although the text was primarily directed to medical physiologists. At that time the comparative anatomy of internally secreting glands attracted much attention, just as several decades previously, comparative anatomy had played a major part in the development and establishment of evolutionary theory. Now it was thought that comparative histology of vertebrate endocrine glands might be able to play a part in medical science. Similarly, in the early part of this century the study of comparative physiology was not neglected, for in 1906 Schafer and Hering demonstrated that extracts made from the pituitary gland of cod produced kidney dilation and diuresis when injected into a dog, just as did extracts made from mammalian posterior pituitary lobes.

Vertebrate endocrinology, however, remained firmly as a 'medical' subject for many years, in fact until the Second World War. This was in spite of the fact that before 1940 noted biologists such as Julian

Huxley had attempted to discuss chemical regulation and the hormone concept in a wider biological context.

It was in 1948 that the first text-book of *General Endocrinology*, written by C.D. Turner, was published to 'present the general and comparative aspects of endocrinology in a manner which would meet the needs of students specialising in the biological sciences'. Research in comparative endocrinology, as it became known, proliferated at this period and the first international symposium was held in 1954 at Liverpool, UK, to be followed by a larger meeting in 1958 held at Cold Spring Harbour, New York. The years 1962-63 were vintage years for the publication of texts of comparative endocrinology with *A Textbook of Comparative Endocrinology* by A. Gorbman and H.A. Bern (Wiley, New York); *Animal Hormones* by Penelope M. Jenkins (Pergamon, Oxford) and *General and Comparative Endocrinology* by E.J.W. Barrington (Oxford University Press, London). Since this period the text *Comparative Vertebrate Endocrinology* by P.J. Bentley (Cambridge University Press, Cambridge) published in 1976 has become perhaps the best known treatment of the subject.

The aims of all these texts were to provide information on, and to establish, a branch of endocrinology which was comparative and general and not necessarily related to medicine. The prime academic objective of comparative endocrinology, according to Bentley, is to reconstruct evolutionary pathways by the study of extant species. Barrington believed that the comparison should be developed on two fronts, the hormonal and taxonomic, and as a result 'we shall hope to extract from the variability that is so characteristic of animal life some statement of general principles which will be reinforced by excursions into evolutionary speculation'. Barrington, quoting William Harvey as an advocate of the comparative approach to medicine, also held the view that 'the comparative treatment of animal function can contribute to the understanding of human physiology and, indeed, is ultimately essential if that understanding is to be reasonably complete'. It was, however, the evolutionary interest of vertebrate endocrinology rather than the medical interest that prevailed with most investigators during the 1950s and 1960s. One of the most interesting evolutionary observations that was made at this time was that of the distribution and chemical structure of neurohypophysial peptides. The chemical structures of these hormones vary slightly but significantly and many differences are apparent between these hormones in fishes and tetrapods. Interestingly, though, the structure of these hormones present in lungfish, which are regarded phylogenetically as being

closer to the tetrapod line than other fish, are similar to tetrapods. Also growth hormone and prolactin of lungfish are chemically more like those seen in tetrapods than in other fishes. The concept of homology has provided a fruitful area of research for the comparative endocrinologist.

For many years workers with birds and mammals (other than laboratory mammals) have allied themselves with the needs of agriculture, for example in the study of the hormonal control of lactation in the cow and with the study of the endocrinology of egg laying in poultry. This has meant that comparative vertebrate endocrinology has been mainly 'lower' vertebrate endocrinology with research concentrated on reptiles, amphibia and fishes.

Recently with the world-wide development of scientifically based fish-farming and aquaculture the endocrinology of fishes has taken a new turn. For many years the aim of studying fish hormones was either to support medical science (fish insulin was considered for the treatment of diabetes in the 1920s) or to establish academic and perhaps evolutionary principles. Today, though, many investigators of fish hormones now consider their research to be largely directed towards fish farming and ranching, just as their colleagues working with poultry or cattle see their work in relation to animal husbandry. It is for the student of aquaculture, fish-farming, fisheries and fish biology that this book is mainly directed. There is no attempt to present fish hormones as part of an evolutionary pattern related to the phylogeny of the group. It is necessary, however, for an aquaculturist or a fish-farming research worker to have some knowledge of the form and function of the glands and hormones that control, for example, growth, egg laying and protein deposition in fish.

In this book I do not attempt to define the basic concepts and content of endocrinology; all the texts mentioned above have done this, as have many more. Thus it is assumed that the reader will have a basic knowledge of endocrinology and relevant anatomy, physiology and biochemistry. Finally no attempt has been made to give a complete list of original research references, there being far too many to include in a book of this size. Suggestions though have been given to readers for extending their reading by the listing of more recent research reports, reviews and symposia. It is hoped that those who, for whatever reason, wish to investigate any aspect of fish endocrinology in more depth will find this bibliography a satisfactory point of departure. References will also be found in the legends to many of the text figures giving a further source of information for the reader.

**A Note on Nomenclature**

Whenever possible both the generic and specific names of fish are used. However, where only the generic name has been given in the original work this name has been used. In a few cases the name of a fish has changed. This particularly refers to the tilapias where taxonomic revision during the past few years has resulted in the same fish being called by different generic names. Today it is accepted that the mouth-breeding tilapias belong to the genus *Oreochromis*. Thus, *Tilapia mossambica = Oreochromis mossambica*. However, the generic name used by original investigators has been retained in each case in this text.

Classification should reflect evolutionary relationships, which in turn should help to explain the significance of physiological adaptations of fishes. However, due to limited knowledge of the evolution and biology of taxa higher than at the species level, classification is sometimes arbitrary. Classifications of fishes, taking into account modern knowledge of morphology, physiology and evolution, have been proposed in Greenwood, Miles and Patterson (1973) and Nelson (1976).

# ACKNOWLEDGEMENTS

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# 1 THE PITUITARY GLAND

## Introduction

The pituitary gland is a neuro-epithelial complex structure which is
present and functional in all groups of vertebrates. The part having
its origin as nervous tissue is known as the neurohypophysis while
that part of epithelial origin is known as the adenohypophysis.
However, the possible evolutionary origin of this gland before it is
seen in its most simple form in the cyclostomes is a matter for
speculation. The fossil record of vertebrates' ancestors to our pre-
sent day fishes tells us nothing about this gland. It is to the living
protochordate groups of animals (*Amphioxus* and the tunicates)
that attention must be turned if some plausible explanation is to be
attempted of how the pituitary gland evolved. *Amphioxus* has pro-
vided biologists with a very valuable example of a chordate in all
its simplicity and it is this animal that provides a clue to the origin
of the pituitary. If the head region of *Amphioxus* is examined
(Figure 1.1) there are two organs which attract attention. These
are the infundibular organ and Hatschek's pit. These two struc-
tures, the first a neural component and the second an epithelial
derivative may be homologous to the neurohypophysis and the
adenohypophysis of fishes. Situated in the floor of the anterior end
of the nerve cord of *Amphioxus*, the cerebral vesicle, is a group of
slender cells known as the infundibular organ which contain cer-
tain granules. These granules stain with a dye which also stains the
granules contained in neurosecretory cells, such as those found in
hypothalamus and neurohypophysis of vertebrates. However, as
has been pointed out many times similar staining reactions are no
evidence for homology of cells. Nevertheless it is tempting to
suggest that here may be the origin of the neurohypophysis.

Hatschek's pit of the adult *Amphioxus* is part of the complex of
ciliated tract known as the wheel organ, which assists in the filter-
feeding of the animal. In the young, pre-metamorphic *Amphioxus*
there is a depression in the superficial ectoderm of the under sur-
face of the head in front of the mouth. This is known as the pre-
oral pit. For a short time in development this pit connects with the
left anterior head cavity of the first coelomic pouch before forming

Figure 1.1: Diagrammatic Representation of the Head Region of *Amphioxus* to Show Position of Infundibular Organ and Hatschek's Pit. PS, pigment spot; HP, Hatschek's pit; NC, nerve cord; N, notochord; IO, infundibular organ; WO, wheel organ; V, velum; P, pharynx.
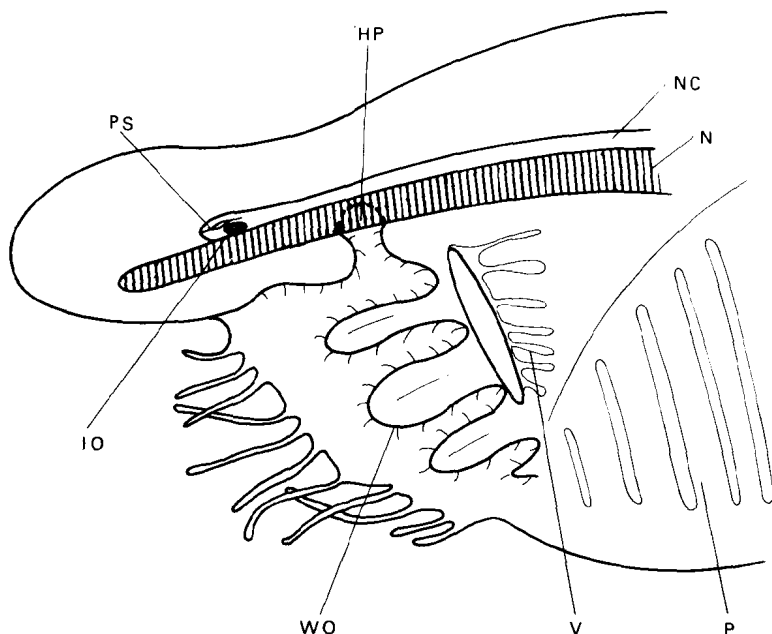


the wheel organ. If one turns now to the development of the pituitary in the elasmobranch *Torpedo*, and looks at the hypophysis it is found that the hypophysis opens into the first pair of coelomic cavities. Thus in the development of Hatschek's pit there is a very similar stage to that in the development of the adenohypophysis of an elasmobranch. It would seem reasonable to homologise Hatschek's pit, part at least, with the adenohypophysis and the pre-oral pit with Rathke's pouch (Figure 1.2).

The tunicates or sea squirts (Urochordates) have also been examined as animals that might possibly contribute to our understanding of the origin of the pituitary. This group possesses a large neural ganglion which lies at the anterior end of the pharynx. Between this ganglion and the pharynx lies an organ called the sub-neural gland which opens via a ciliated funnel into the pharynx. Barrington has speculated that this organ could have

Figure 1.2: The Relations in Transverse Section Between the Pre-oral Pit of *Amphioxus* and the Hypophysis (Rathke's Pouch) of Vertebrates. H, hypophysis; POP, pre-oral pit; LAHC, left anterior head cavity; PMS, premandibular somite; LL, lateral lobe; EM, eye muscle.
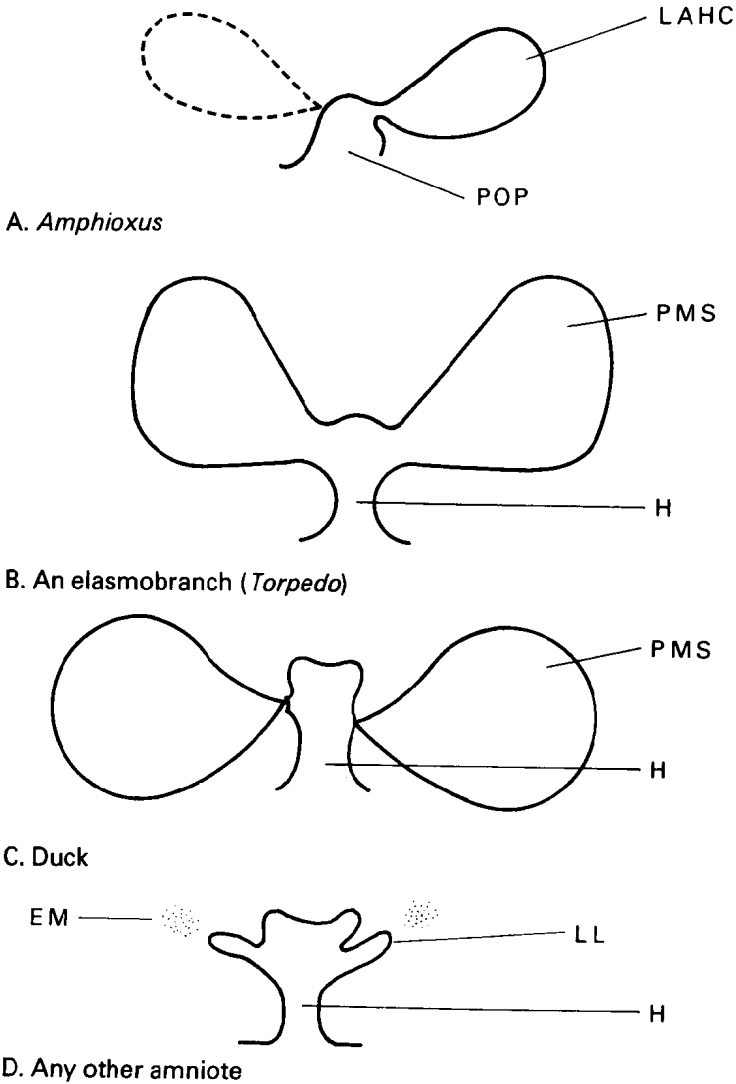


A. *Amphioxus*

B. An elasmobranch (*Torpedo*)

C. Duck

D. Any other amniote

become closed off from the outside world and evolved into an internally secreting gland responding to chemical stimuli from the central nervous system. No experimental investigation, however, in spite of a number of attempts, has demonstrated unequivocally the presence of vertebrate-like hormones in this complex. We have said that the pituitary consists of two parts, the neural component, the neurohypophysis — the down-growth from the floor of the diencephalon, and the ectodermal component — the up-growth or Rathke's pouch, forming the adenohypophysis. However, it must not be forgotten that these two components enclose between them mesoderm which gives rise to the blood vessels of the pituitary. The development, form and function of all these components must now be traced in fishes.

## The Pituitary Gland of the Agnatha (Lampreys and Hagfish)

### Embryology and Vasculation

The embryology of the cyclostome pituitary has been elucidated by studies of the development of lampreys particularly *Lampetra fluviatilis*, *Lampetra planeri* and *Ichthyomyzon fossar*. The detailed stages in the development of the pituitary of the myxinoids is entirely unknown, larval stages of these animals having not yet been found in sufficient numbers for such a study to be carried out. The development of the lamprey pituitary must serve as a model for all cyclostomes.

The adult lamprey pituitary has a simple structure and for whilst its adenohypophysis is histologically subdivided its neurohypophysial component is even more simple than that of myxinoids. In *Myxine glutinosa* the neurohypophysis projects backwards from the base of the brain as a tube-like structure, whereas in the lampreys the neurohypophysis is distinguished only as a slight thickening of the floor of the third ventricle (Figure 1.3).

The lamprey adenohypophysis arises as a thickening of the ectoderm under the forebrain of the embryo. This thickening or placode evaginates and develops into the neurohypophysial stalk. This is the adenohypophysial analogue which is closely associated with the olfactory placode. As this stalk develops it moves round gradually to the dorsal region of the head while the solid stalk of cells comes in contact with the developing neurohypophysis and differentiates into the three regions of the adenohypophysis (Figure 1.4). The cord of cells forming the stalk remains in this

Figure 1.3: Diagrammatic Representation of Sagittal Section of the Pituitary of (a) a Lamprey and (b) a Hagfish. A, adenohypophysis; BV, blood vessels; C, cartilaginous base of skull in which islets of adenohypophysis cells are embedded; PI, pars intermedia; PPD, proximal pars distalis; RPD, rostral pars distalis; III, third ventricle.
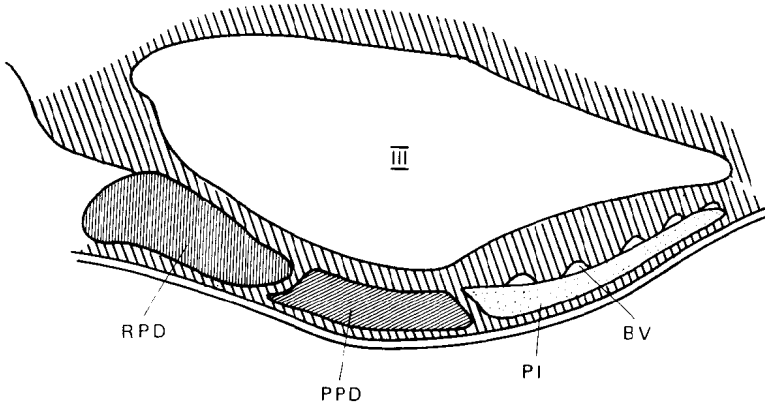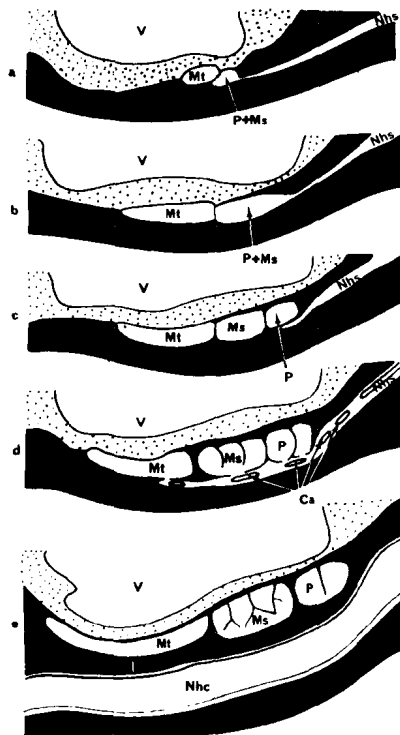


(a) Lamprey
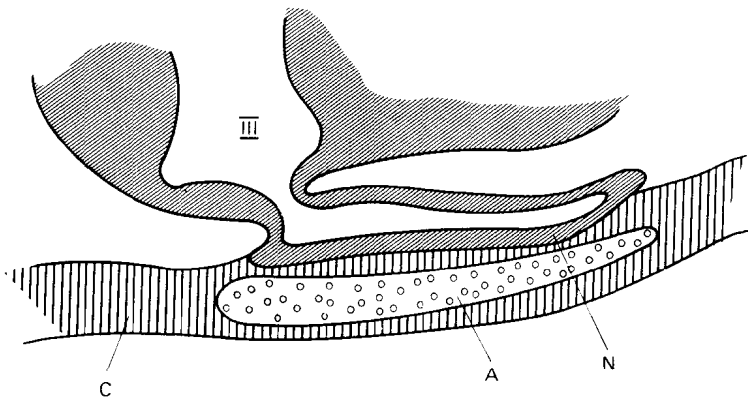


(b) Hagfish

form during the larval ammocoete stage of the lamprey, a stage which may last for a number of years. On metamorphosis cavities appear in the stalk. These cavities coalesce to form the neurohypophysial canal which is open to the dorsal surface of the head.

Figure 1.4: Diagram of the Development of the Lamprey Pituitary Gland with Special Reference to the Association of the Nasohypophysial Stalk with the Adenohypophysis. a, b, and c. Ammocoete stages indicating the development of the adenohypophysial components from the nasohypophysial stalk. d. Early transforming lamprey indicating connections between the nasohypophysial stalk and regions of the adenohypophysis. e. The definitive lamphrey hypophysis after transformation. Ca, cavitation of stalk shown in (d); Ms, meso-adenohypophysis (= proximal pars distalis); Mt, meta-adenohypophysis (= pars intermedia); Nhc, nasohypophysis canal; P, pro-adenohypophysis (= rostral pars distalis); P + Ms, presumptive pro-and meso-adenohypophysis; V, IIIrd ventricle.



Source: from Larsen, L.O. and Rothwell, B. (1972) Adenohypophysis. in M.W. Hardisty and I.C. Potter (eds.) *The Biology of Lampreys,* vol. 2. Academic Press, London, pp. 1-67.

The adenohypophysis of lampreys develops into three regions (Figures 1.3a and 1.4e). Homology of these regions with those of other groups of fishes is far from clear, and at the late larval, premetamorphic stage the connection between the stalk and the pituitary is lost and the stalk becomes separated from the adenohypophysis by a strip of connective tissue. However, at metamorphosis the connection becomes re-established with all three regions. It has been suggested by Larsen and Rothwell that this re-association might provide a significant pool of undifferen-

Figure 1.5: Diagram of Sagittal Section of Brain and Pituitary Gland of an Ammocoete Embryo of the Lamprey, *Petromyzon marinus*, Showing Distribution of Hypothalamic Neurosecretory Cells and Axons. Anterior to the left. 1: ventricle III, 2: subcommissural organ, 3: choroid plexus, 4: habenula, 5: pineal body (parapineal not represented), 6: preoptic nucleus, 7: nasopharyngeal stalk, 8: blood vessel, 9: optic chiasma, 10: rostral zone of pars distalis, 11: preoptic neurosecretory axons ending above the rostral zone, 12: proximal zone of pars distalis, 13: preoptic neurosecretory axons forming the preoptic-hypophysial tract, 14: preoptic neurosecretory axons which enter the neurohypophysis from a lateral direction, 15: pars intermedia, 16: neurohypophysis, 17: infundibular cavity, 18: axons from the posterior hypothalamic neurosecretory nucleus to the neurohypophysis, 19: posterior hypothalamic neurosecretory nucleus, 20: preoptic neurosecretory axons extending into the hind brain.
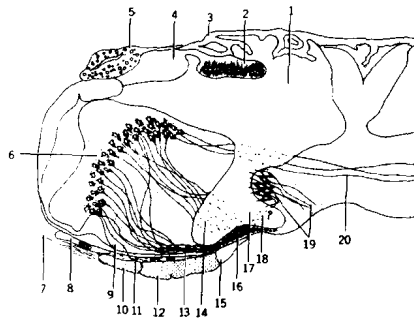


Source: Oztan, N. and Gorbman, A. (1960) The hypophysis and hypothalamo-hypophysial neurosecretory system of larval lampreys and their response to light. *J. Morphol.*, *103*, 243.

tiated tissue from which further adenohypophysial tissues could be differentiated. The pituitary continues to develop during metamorphosis.

As previously mentioned, the blood supply of the lamprey pituitary develops between the neurohypophysis and adenohypophysis forming a plexus with branches penetrating both into the adenohypophysis and into the connective tissue between the three regions. A knowledge of vasculation is important for the understanding of pituitary function. The blood capillaries penetrating the adenohypophysis are surrounded by loose pericapillary connective tissue through which hormones and metabolites must pass. The capillary penetration is complex. The arteries supplying the pituitary are derived from branches of the internal carotid artery and there appear to be two venous drains. Gorbman has shown in lampreys that the vascular system of the neurohypophysis and pars intermedia is separate from that of the pars distalis, and has separate venous drains. He does not regard the region between the pars distalis and the anterior neurohypophysis as being one in which an efficient neurovascular exchange can develop such as one sees in the median eminence of higher vertebrates. Thus there appears to be no hypophysial portal system taking blood and hormonal products from the neurohypophysis to the pars distalis. However, between the pars intermedia of lampreys and the posterior region of the neurohypophysis there does appear to be an extensive capillary network which could allow neurosecretory products of the neurohypophysis to reach the pars intermedia. Electron microscopy studies indicate that in lampreys that there are no neuronal units of any kind crossing between the neurohypophysis and adenohypophysis.

## The Cytology of the Adenohypophysis

Before examining the neurosecretory system and neurohypophysis of cyclostomes the cytology will be considered. Whereas nothing is known of the embryology of the myxinoid pituitary its morphology and cytology in the adult is known. As mentioned previously although the neurohypophysis of myxinoids appears to be better developed than that of lampreys the adenohypophysis is less differentiated. For here in the myxinoids this component of the gland is composed solely of follicles and clusters of cells embedded in connective tissue and there is no differentiation between pars distalis and pars intermedia. Indeed it is held that there is no true pars intermedia in hagfish and certainly there is no evidence that