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RANJANA MEHTA AND K. K. TANDON

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CONTENTS

Introduction

Cyprinoids form a bulk of the superorder Ostariophysi—one of the most clearly defined major groups of recent teleosts (Greenwood *et al.* 1966). These fishes have undergone a number of interesting morphological modifications in various directions in commensurate with the change in environment. The taxonomic studies of the cyprinids are based mostly on external morphological characters and the exact systematic position of some genera and species still remains in a confused state.

Attempts have, therefore, been made by various workers to supplement more suitable characters for justification of divisions of the family into groups and tribes on the basis of osteology. Regan (1911) is of the opinion that external morphological characters are not sufficient enough in the taxonomy of cyprinids. He, therefore, gives a phylogenetic key to different subfamilies, based on the characters of skull, Weberian apparatus and the pectoral girdle. Hence, the osteological studies are important tools in the hands of fish taxonomists.

Sorescu (1975) and Howes (1978) have tried to assesss the Phylogenetic positions of some subfamilies like Danioninae, Cultrinae, Leuciscinae, Gobioninae, Barbinae and Cyprininae. But their work is restricted mainly to foreign genera. Although Ramaswami (1948, 1952a, b, c, d, 1953, 1955a, b) has carried out considerable work on the osteology of Indian cyprinoids, a perusal of literature reveals that there is still enough scope to undetake such studies, especially on species which inhabit high altitude areas. Further, Ramaswami's work does not clearly indicate phylogenetic relationships of the species, the genera and the higher taxa. It has been rightly pointed out by Greenwood *et al.* (1966) that it is very necessary to work out the osteological aspects in long series of closely related species and genera to fill in the lacunae in our knowledge of relationships of this group of fishes.

Of the twelve species of cyprinids investigated, the osteology of six species has not been attempted so far and the data available on the rest seem to be insufficient for explaining their phylogenetic relationship. An attempt has been made to determine the osteological modifications in relation to ecological niches and to trace the phylogenetic relationships of each group. A key to identification of subfamilies and genera of the Cyprinidae, based on present osteological studies, has also been erected.

BRIEF REVIEW OF LITERATURE

The osteological studies on teleost have attracted the attention of many Ichthyologists, important references being those of Goüan (1770), Weber (1820), Agassiz (1833), Hallmann (1837), Muller (1842), Owen (1848), Stannius (1854), Huxley (1864, 1876), Parker (1873), Masse (1873), Stöhr (1884) and Wright (1884).

McClelland (1842) was a pioneer worker who made use of osteological studies in separating the tribes and groups of fishes in family Cyprinidae. The significant contributions on the endoskeleton studies are those of Sagemehl (1891), Regan (1911) and Sarbahi (1933). In the middle of present century, Ramaswami (1948, 1952a, b, c, d, 1955a, b) and Harrington (1955) could make use of many osteological characters, viz. osteocranium apparatus in the taxonomy of family Cyprinidae. Recently, workers like Vashist and Verma (1968), Sorescu (1975, 1978) and Howes (1978) have made good contributions by studying osteocranium and associated structures.

The researchers who have restricted their studies to osteocranium or only parts of it are Hubbs (1919, 1926), Gregory (1933), Eaton (1935), Matthes (1963), Saxena and Khanna (1963), Saxena and Bakshi (1964), Das and Daftari (1967a, b), McAllister (1968), Nelson (1969), Tiwari (1972), Mirza (1973), Gosline (1973, 1975) and Takaya (1974).

The studies of Weberian apparatus and associated structures from taxonomic, phylogenetic and functional aspects have been made by Bridge and Haddon (1893), Sachs (1912), Hora (1922), Evans (1925), Chranilov (1927, 1929), Marshal and Jones (1952), Alexander (1962, 1964), Lal (1964, 1971) and Das and Peers (1969).

The girdles and caudal skeleton have been studied by Haller (1905), Whitehouse (1910, 191), Goodrich (1930), Mukerji (1935), Shelden (1937), Barrington (1937), Eaton (1945), Saxena and Chandy (1965), Nybeline (1972), Roberts (1972), Shukla and Verma (1972) and Ansari and Khan (1975).

MATERIAL AND METHODS

The present investigations were conducted on twelve Indian cyprinids (Figs. I to XII). Of these, seven species belonging to subfamily Schizothoracinae, viz. *Schizothorax richardsonii* (Gray), *Diptychus maculatus* Steindachner, *Schizopygopsis stoliczkae* Steindachner, *Ptycobarbus conirostris* Steindachner, *Schizothoraichthys micropogon* (Heckel), *Schizothoraichthys esocinus* (Heckel) and *Schizothoraichthys labiatus* (McClelland) are representatives of the Palaearctic fauna, confined to the Indus

drainage system in the Western Himalayas ; whereas four species, viz. *Labeo dero* (Hamilton), *Garra lamta* (Hamilton) (subfamily : Cyprininae), *Rasbora daniconius* (Hamilton) and *Aspidoparia morar* (Hamilton) (subfamily : Rasborinae) inhabit the lower Himalayas while the one belonging to subfamily Cyprininae, viz. *Schismatorhynchus nukta* (Sykes) is a representative from South India (Fig. XIII).

Cast net was used for collection. The specimens ranged from 15 cms. to 30 cms. The observations on each species are based on 10-15 specimens preserved in formalin and stored in alcohol. The standard dry method and alizarin technique have been used for osteological preparations. Figures of the disarticulated bones of the osteocranium, Weberian apparatus and appendicular skeleton have been drawn with the help of a camera lucida.

As far as possible, Hora and Mukerji's (1970) classification for the Cyprinidae, Harrington's (1955) terminology for the osteocranium, Tilak's (1961) for the Weberian apparatus, Saxena and Chandy's (1965) for the pelvic girdle and Howes's (1978) for the pectoral girdle and caudal skeleton were followed. The abbreviations of the journals are given according to the World list of Periodicals (1974).

OBSERVATIONS

A. Osteocranium

The osteocranium is a well ossified, compact structure with a large number of replacing and investing bones (Table I). The following regions may be identified in the osteocranium :

1. *NEUROCRANIUM*

It encloses and protects the brain and sense capsules. When viewed from above, the neurocranium is a wedge-shaped structure. It is about 2.15 to 2.70 times as long as it is broad in schizothoracine fishes while it is 2.0 to 2.20 times as long as it is broad in the rasborine genera. In the cyprinine genera, the skull is 1.8 to 2.0 times longer then it is broad. For the sake of convenience, the neurocranium can be divided into following four regions as described by Harrington (1955) :

I. Olfactory Region
II. Basicranial Region
III. Orbital Region
IV. Otic Region

2. *BRANCHIOCRANIUM*

It supports the visceral arches and can be conveniently divided into three regions (Table I).

(i) Oromandibular region

(ii) Hyobranchial region

(iii) Opercular bones

B. Weberian Appartus

The first four vertebrae of the vertebral column are highly modified and connect the swim bladder with the auditory region of the fish. The fourth vertebra forms a support for septum transversum. The swim bladder is present in the body cavity.

C. Girdles

Two pairs of girdles are present. The anterior-pactoral ones- are situated just behind the gills and support the ventral aspect of pharyngeal region. The posterior-pelvic ones-are placed just anterior to anus.

D. Caudal Skeleton

In the caudal fin, the major skeletal supports are the neural and the haemal arches of the distal elements of the vertebral colum. The additional radial elements are present but these are seldom well developed ; the fin proper consists of a stout web of skin supported by powerful lepidotrichia. The cyprinid fishes are characterized by their homocercal tail.

A. Osteocranium

1. *NEUROCRANIUM*

I. *Olfactory Region* :

This is the anteriormost region of the neurocranium and includes bones which have developed in relation to the snout and nostrils. Supraethmoid, ethmoid, kinethmoid and the prevomer are the unpaired bones whereas the nasals, the lateral ethmoids and the preethmoids are the paired bones of this region.

Supraethmoid (Figs. 1-24) : It is a broad, median bone, firmly united with the frontals suturally. It is shield-like, rectangular or squarish bone, forming the roof of cranium. It may have a central depression

in some species. The supraethmoid is comparatively broader in *Schizothoraichthys esocinus*, *Schismatorhynchus nukta*, *Aspidoparia morar* and *Rasbora daniconius*. In *Aspidoparia morar*, the anterior medial end bears pits while the sides extend out as thin extensions.

Ventrally, the supraethmoid is fused with the ethmoid. Its anterior part usually bears a median notch which is bounded on the two sides by small, pointed, horn-like processes. The anterior notch is narrow in *Schizothorax richardsonii*, *Diptychus maculatus Ptycobarbus conirostris*, *Schizothoraichthys esocinus*, *Schismatorhynchus nukta* and *Labeo dero*. In *Schizopygopsis stoliczkae*, *Schizothoraichthys micropogon* and *Schizothoraichthys labiatus*, the anterior north is shallow ; whereas it is deeply grooved in *Aspidoparia morar* while deep and saucer-shaped in *Rasbora daniconius*. The notch is altogether absent in *Garra lamta*.

The supraethmoid presents a winged appearance in schizothoracine fishes and is medially depressed. In *Labeo dero* and *Schismatorhynchus nukta*, it is narrow anteriorly and broad posteriorly. In *Labeo dero* and *Garra lamta*, it articulates with the frontals at an angle of about 30° whereas this angle is about 85° in *Schismatorhynchus nukta*. In this particular species, it lies in a vertical fashion between the anterior end of the frontals and the ethmoid and does not form the dorsal surface of the cranium.

The lateral chamber for the olfactory organs formed by the lateral extensions of supraethmoid and anterior extensions of the frontals on the dorsal side and the lateral ethmoids on the ventral side is comparatively small in schizothoracine fishes, *Labeo dero* and *Schismatorhynchus nukta* but quite deep in *Garra lamta*. The olfactory chamber in *Rasbora daniconins* and *Aspidoparia morar* is quite small and its base is much reduced. The supraethmoid, as a whole, takes part in lengthening of the skull in schizothoracine and rasborine fishes than in the cyprinine genera under report.

Ethmoid (Figs. 1-12) : Dorsally, the ethmoid supports the supraethmoid for which it forms an elevated platform and ventrally, it is fused with the dorsal aspect of the prevomer. Anteriorly, it articulates with the preethmoids and the prevomer. The ethmoid is much prominent anteriorly in all the cyprinine and schizothoracine genera under report. However, in *Garra lamta*, its anterior border does not extend beyond the anterior border of supraethmoid. In *Aspidoparia morar*, the ethmoid is very much reduced and indistinguishably fused with the anterior horn-like processes of supraethmoid. It does not form the floor of the supraethmoid in both the rasborine genera.

Kinethmoid : It is rod-shaped bone with swollen tips. Its dorsal end bears groove and the ventral surface is somewhat flat. Its ventral tip is embedded in the ligament which connects the rostral process of each maxillary while the dorsal tip is connected to the premaxillaries through a sigmoid ligament. The sigmoid ligament as well as the kinethmoid move dorsoanteriorly or ventroposteriorly, the tips of rostral processes of each maxillary act as fulcrum.

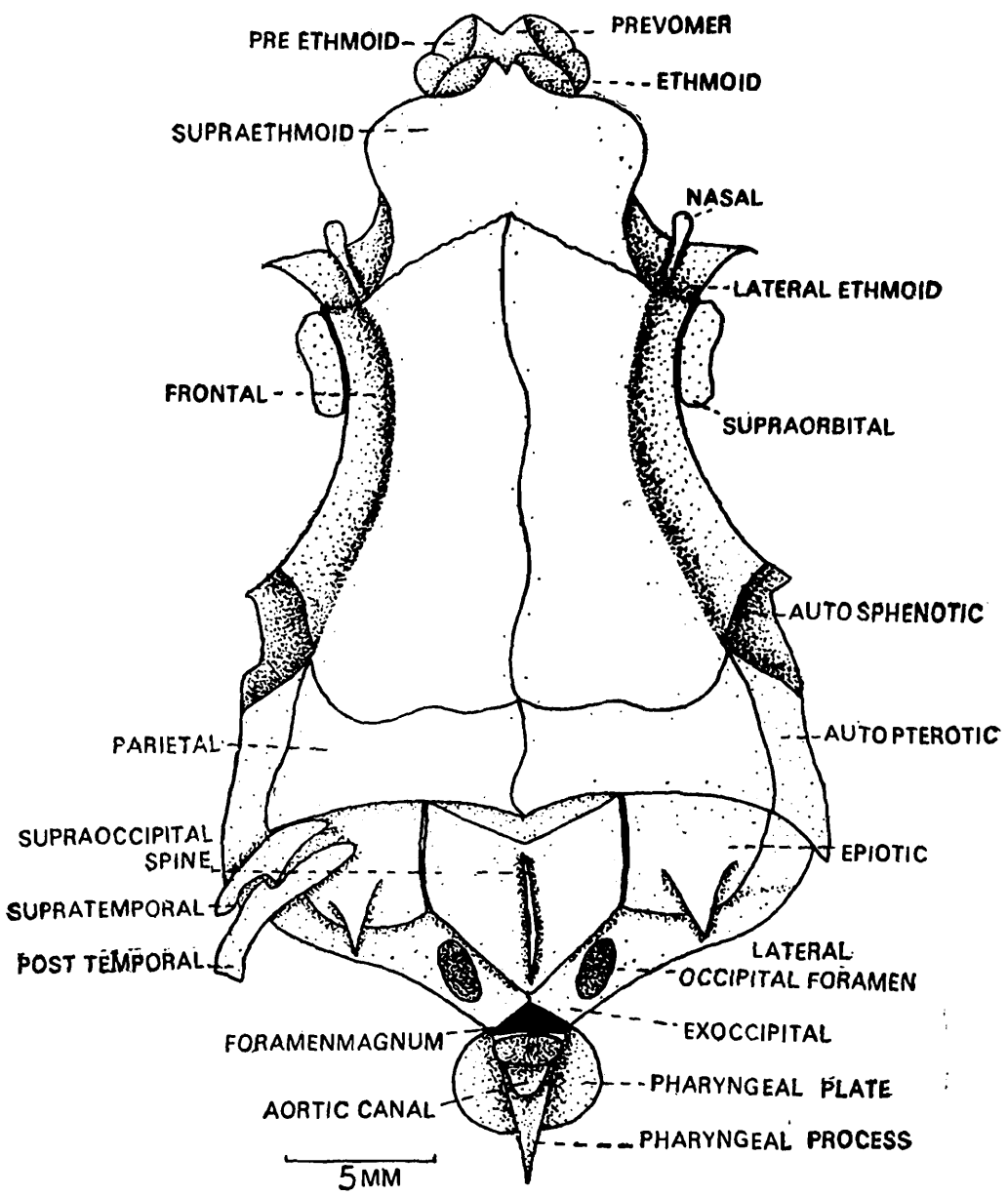


FIG 1

Figs. 1-12. Dorsal aspects of skulls (premaxillaries, maxillaries and suborbital series removed ; supratemporal and posttemporal shown on one side) of *Schizothorax richardsonii, Diptychus maculatus, Schizopygopsis stoliczkae, Ptycobarbus conirostris, Schizothoraichthys micropogon, S. esocinus S. labiatus, Labeo dero, Schismatorhynchus nukta, Garra lamta, Aspidoparia morar* and *Rasbora daniconius* respectively.

The kinethmoid, in retracted condition, lies in a hook-like manner in the anterior part of the supraethmoid. The arrow- shaped bone is well developed in all the schizothoracine fishes except in *Schizothorax richardsonii.* In the cyprinine and rasborine genera, it is also less

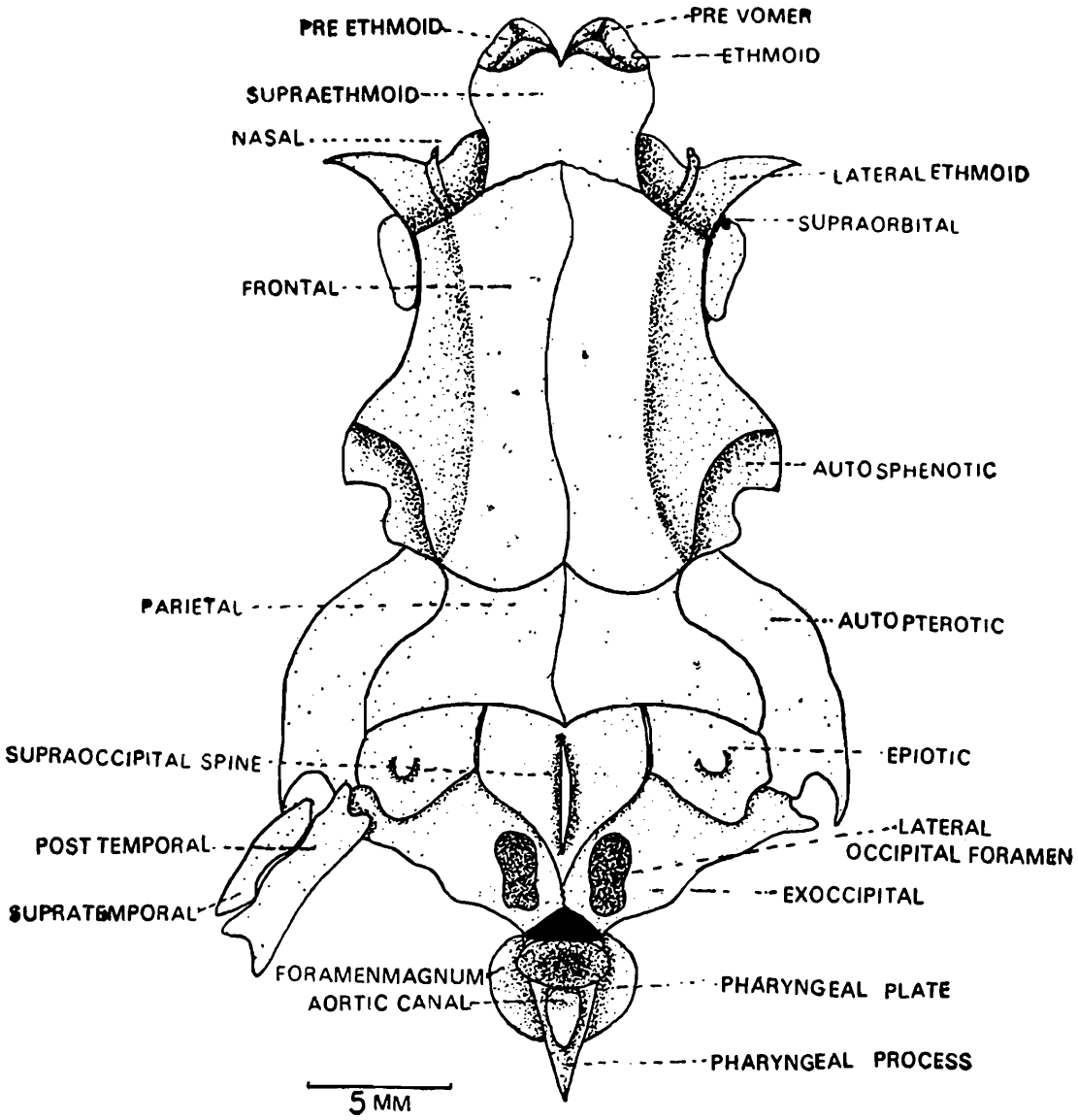


FIG 2

developed and can be compared with the latter species. The sigmoid ligament is small in species where the rostral processes of premaxillaries are large, viz. *Schizothoraichthys* species, *Ptycobarbus conirostris* and *Rasbora daniconius*. In rest of the species, it is in a reverse order.

Prevomer (Figs. 1-24) : It is a horizontal bone, lying on the ventral surface of the skull, immediately in front of the anterior end of parasphenoid and beneath the ethmoid and supraethmoid. It forms the floor of the cranial cavity and fills the deep depressions found beneath the supraethmoid. In *Schizothorax richardsonii*, the width of the prevomer is somewhat uniform whereas in rest of schizothoracine genera, the anterior part is broader than the posterior. In *Schizothorax richardsonii*, *Schizopygopsis stoliczkae* and *Ptycobarbus conirostris*, poste-

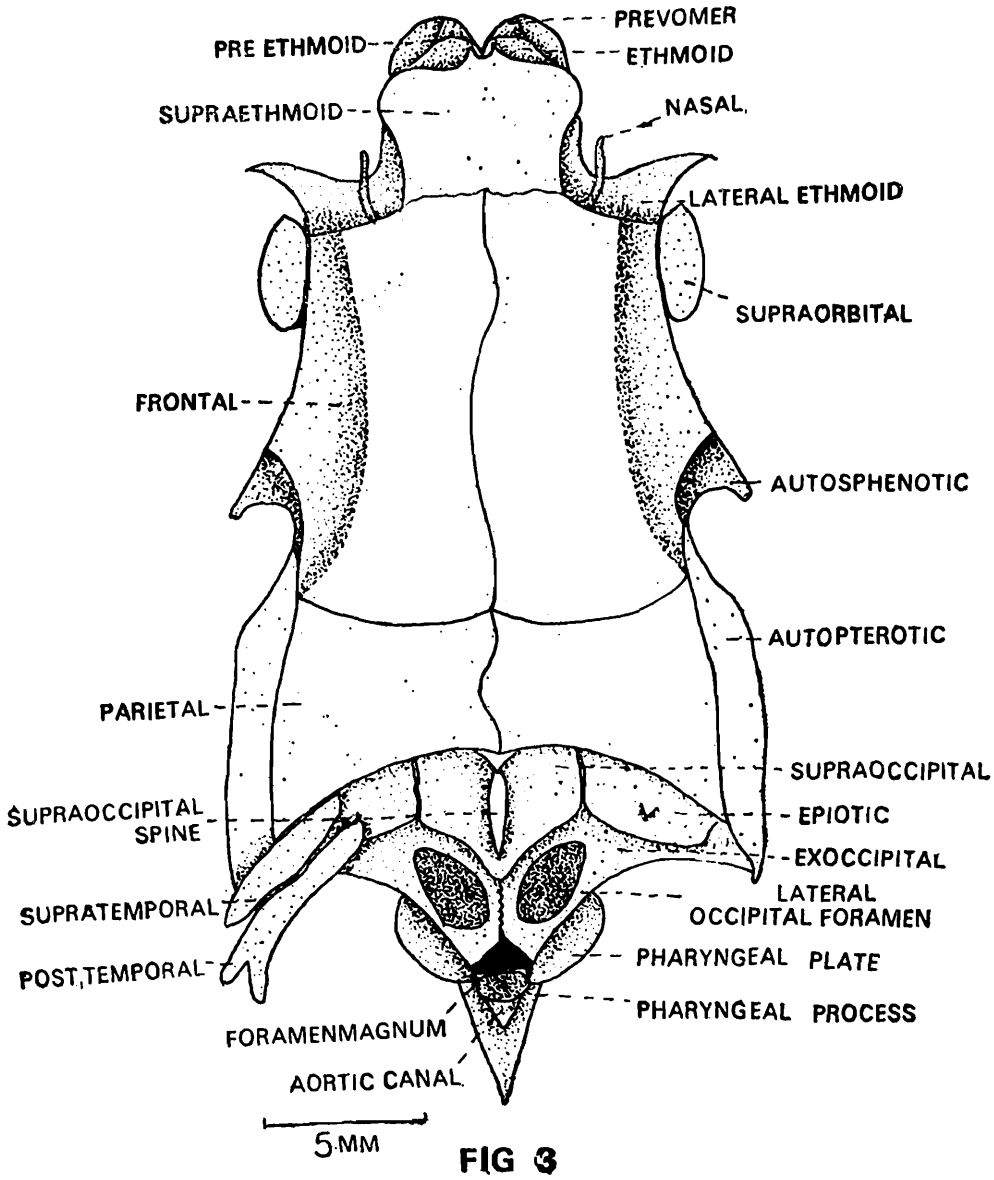


FIG 3

riorly, it reaches up to anterior $\frac{1}{3}$rd part of the supraorbital. In *Diptychus maculatus*, *Schizothoraichthys esocinus* and *Schizothoraichthys labiatus*, it covers nearly two third part of the supraorbital; whereas in *Schizothoraichthys micropogon*, the posterior extremity of the prevomer reaches nearly the posterior border of the supraorbital. In *Labeo dero* and *Schismatorhynchus nukta*, the prevomer covers only the anterior $\frac{1}{5}$th part of the supraorbital, wheraas in *Garra lamta*, it does not even reach the anterior border of supraorbital. In *Aspidoparia morar* and *Rasbora daniconius*, it covers only anterior $\frac{1}{8}$th part of the supraorbital.

Anteriorly, the prevomer bears two lateral processes. In between these two processes, there is a median notch. In *Diptychus maculatus*, there is a slightly raised ridge in the anterior half of the prevomer. In *Ptycobarbus conirostris*, the anterior part of the provomer along with the preethmoids forms a raised hood.

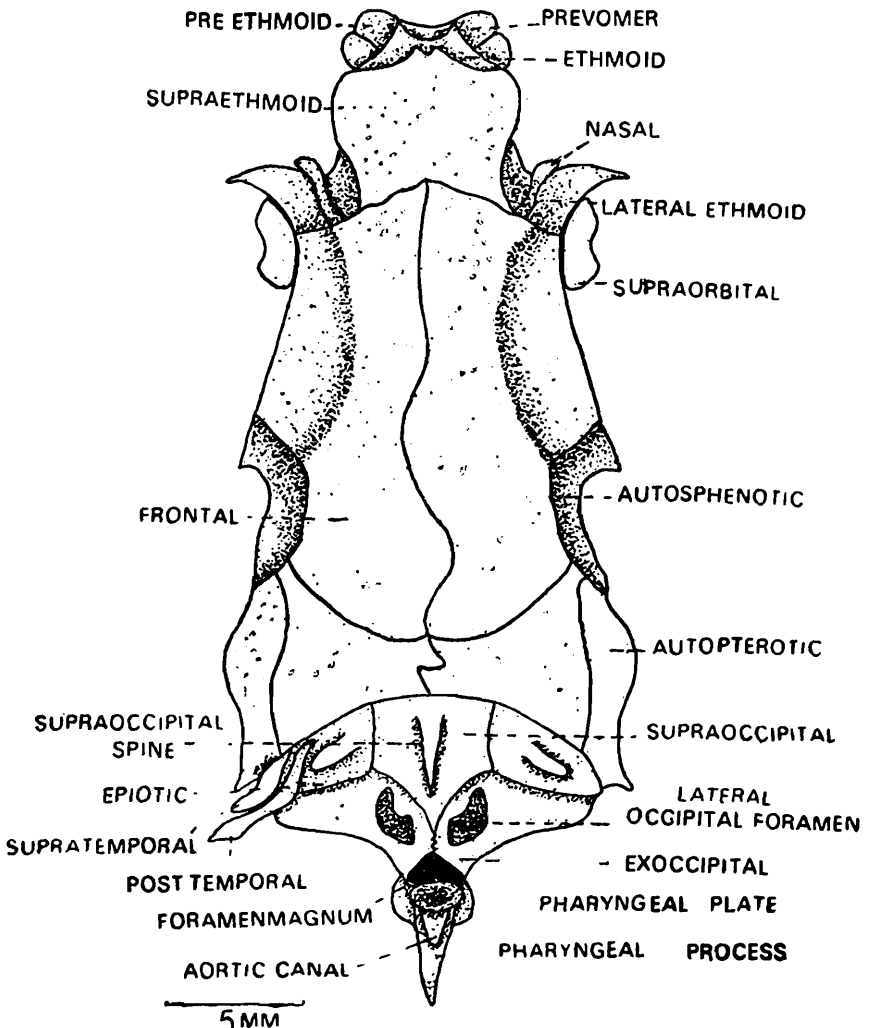


FIG 4

The lateral processes of the prevomer on either side of the notch, support the preethmoids of respective side. Laterally, the prevomer articulates with autopalatines and the lateral ethmoids and posteriorly, with the parasphenoid. In *Labeo dero* and *Schismatorhynchus nukta*, the anterior part of the prevomer is very prominent and bears a deep groove on its ventral aspect. This anterior tip of the prevomer in these two species is 'U'— shaped. The limbs of the 'U' are quite apart in *Labeo dero*. The preethmoids are attached on either side of the posterolateral aspect of the body of prevomer and are different from those of the schizothoracine genera. In *Garra lamta*, the prevomer is a very prominent and broad bone which forms the whole of the anterior part of the ventral aspect of skull. The anterior end of the prevomer is feebly concave and does not form the anterior processes so characteristic of *Labeo dero* and *Schismatorhynchus nukta*. A similar hood as that in *Ptycobarbus conirostris* is present in these cyprinine three genera. The prevomer in *Rasbora daniconius* is a broad bone but reduced in length. The anterior border of the prevomer is deeply concave and it forms

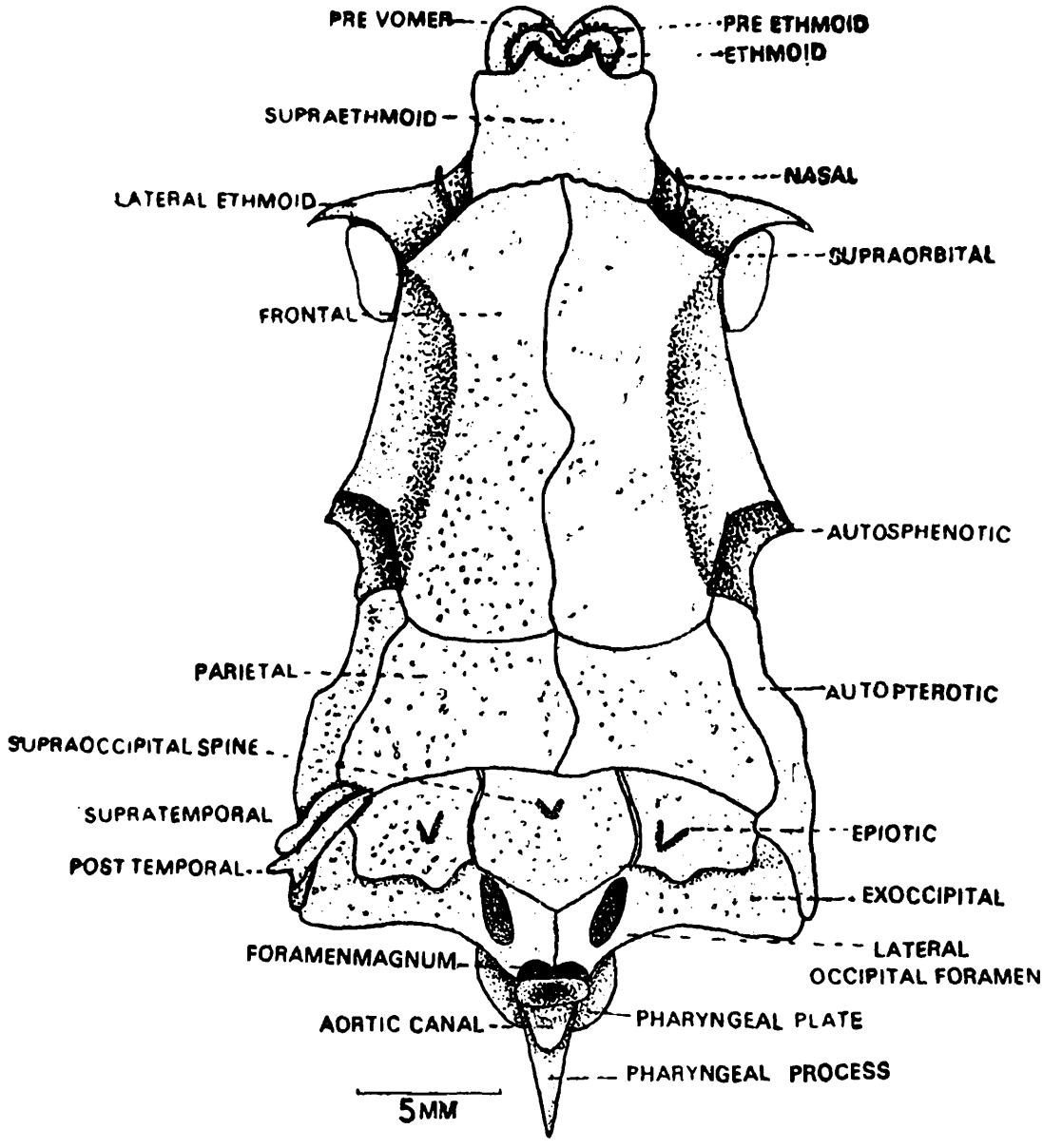


FIG 5

two blunt lateral processes. In *Aspidoparia morar*, the prevomer has a broad anterior and a narrow posterior part.

Nasal (Figs. 1-24) : Each nasal lies on either side of the neurocranium as a small, cylindrical, somewhat tubular bone lying above the olfactory capsule, almost parallel to the supraethmoid. It lies in a notch, formed at the anterolateral corner of the supraethmoid and the adjoining corner of the frontal. In conjunction with the lateral wing of the supraethmoid, it forms the roof of nasal pit and also forms the dorsal border of the nostril.

Laterally, each nasal is connected by ligaments to the lacrymal of its side. It is not directly connected to the neurocranium and has no sutural joints with the adjacent bones but is held in position mainly by

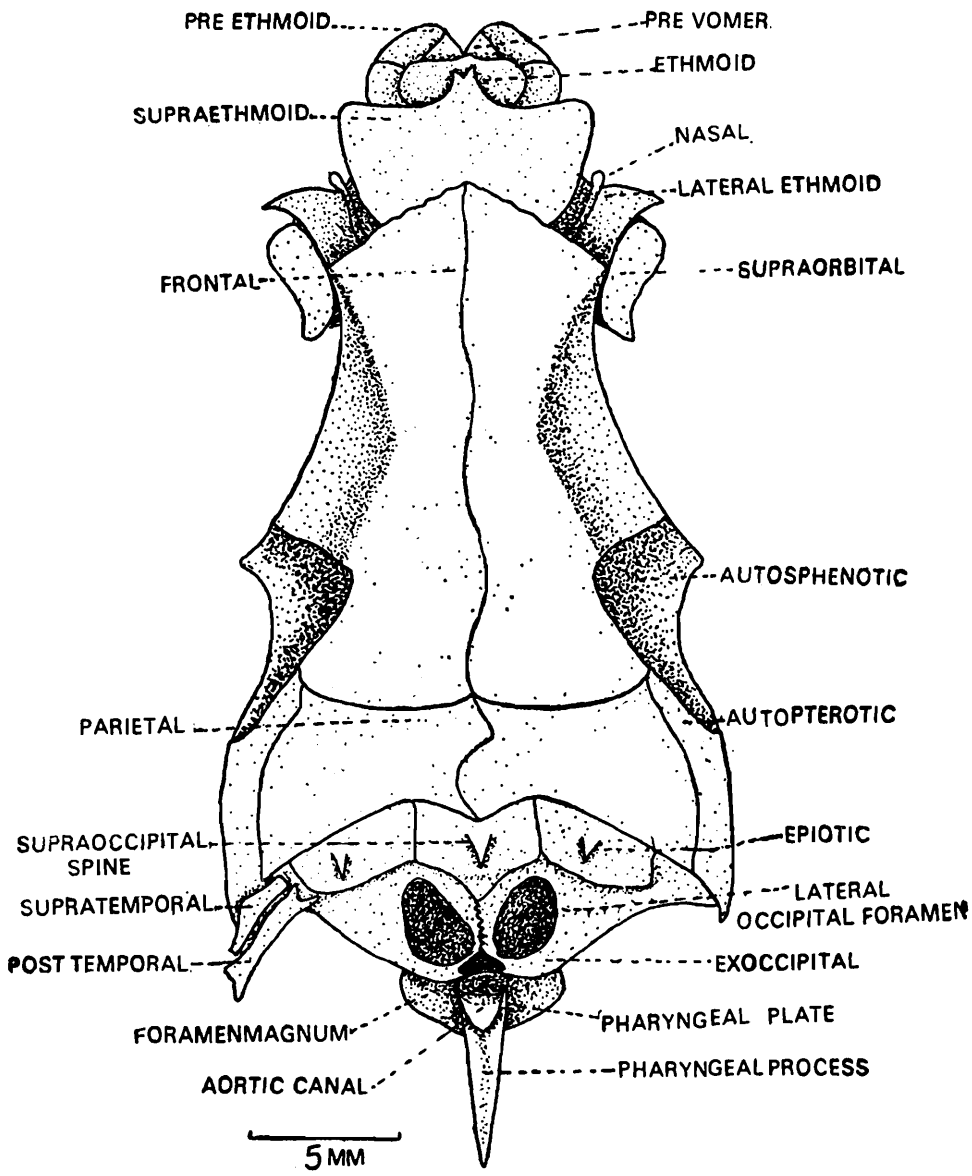


FIG. 6

the connective tissue and, to some extent, by the continuation of the lateral sensory canal which passes through it. The nasal does not show significant differences in the fishes under report.

Lateral ethmoid (Figs. 1-24) : Each lateral ethmoid extends well beyond the lateral margin of the cranium, forming the olfactory capsule and separates the olfactory region from the orbital region. Prefrontals are apparenly absent and may have been completely fused with lateral border of the lateral ethmoid of each side, forming a complex bone (Harrington, 1955). It can be distinguished into (i) a mesial body which is overlain dorsally by the anterolateral portion of the frontal and (ii) a lateral process. The main body of the bone is excavated by a deep olfactory pit which lodges the olfactory sac and opens to the exterior by a double nasal opening situated on its dorsolateral aspect.

Posterioly, the bone forms the anterior boundary of the orbit. The posterior border of lateral ethmoid extends slightly below the articulation of parasphenoid and prevomer in *Diptychus maculatus*, *Schizopygopsis stoliczkae*, *Schizothoraichthys labiatus*, *Labeo dero* and *Schismatorhynchus nukta* but the articulation is deep in *Schizothorax richardsonii*, *Ptycobarbus conirostris*, *Schizothoraichthys micropogon*, *Schizothoraichthys esocinus* and *Garra lamta*. In *Rasbora daniconius* and *Aspidoparia morar*, posterior border of the lateral ethmoid extends deeper.

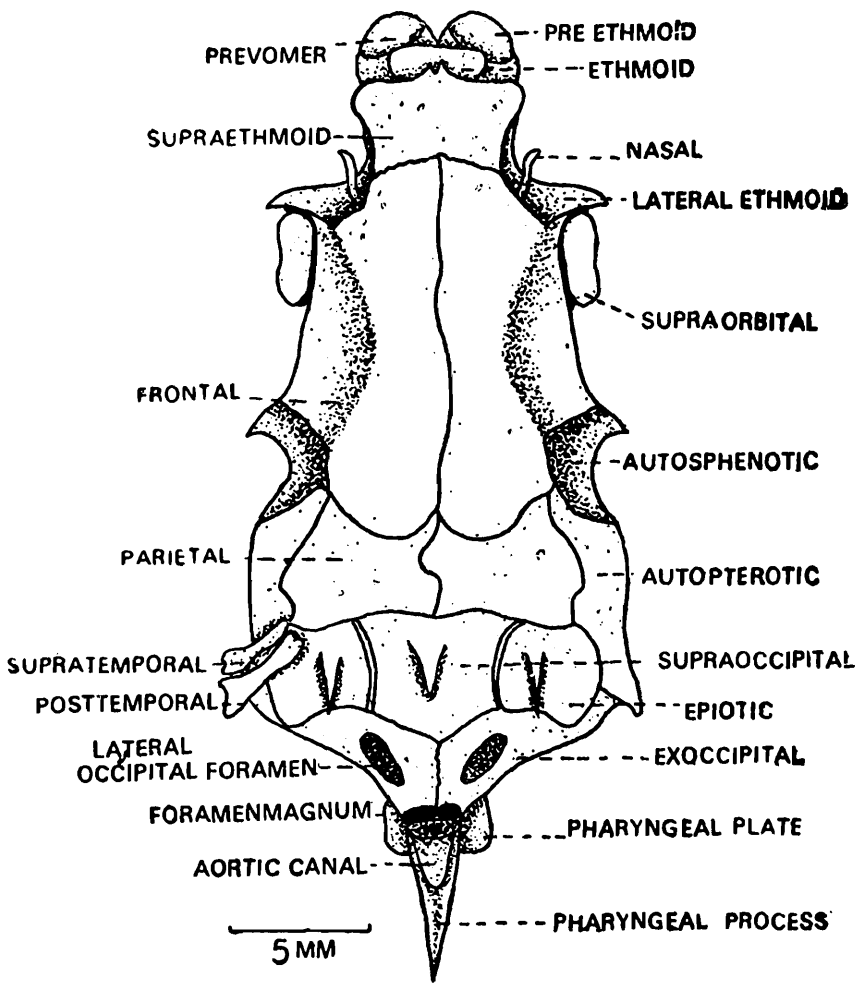


FIG 7

The lateral ethmoid articulates anteromedially with the posterolateral edge of the supraethmoid and posterolaterally, with the anterior surface of the orbitosphenoid. The point of articulation with the orbitosphenoid is narrow in *Schizothorax richardsonii*, *Schizothoraichthys* spp. and *Ptycobarbus conirostris* as compared to those of *Diptychus maculatus* and *Schizopygopsis stoliczkae*. The outer lateral process of each bone articulates anteriorly with the posterlateral margin of each lacrymal. Posteriorly, it is connected to the supraorbital by strong ligaments. The dorsal surface of the lateral process forms a part of the floor of

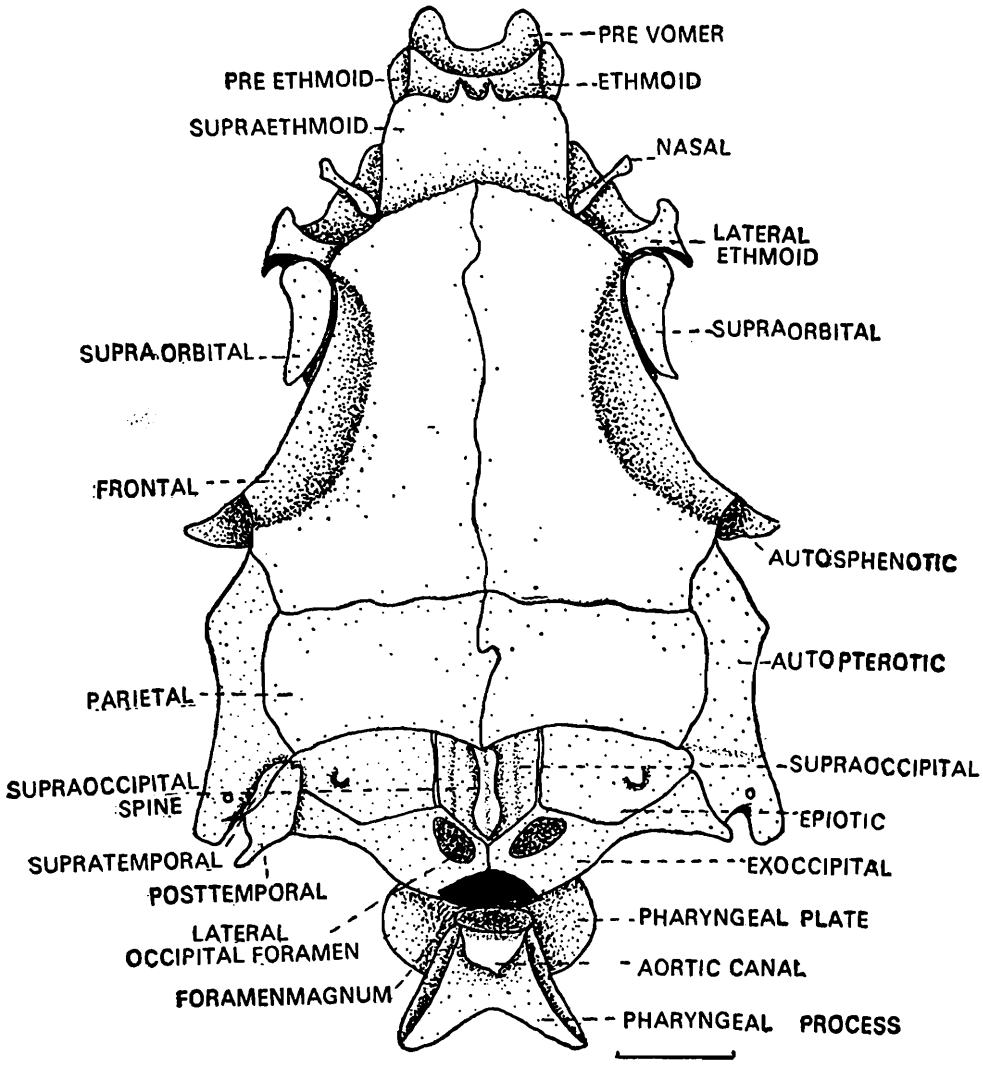


FIG 8

nasal pit. Ventrally, it articulates with the anterior process of parasphenoid. Usually, the tip of the lateral process of the lateral ethmoid points lateroposteriorly in schizothoracine fishes.

In *Labeo dero* and *Schismatorhynchus nukta*, the lateral process forms lateral part of roof of the skull while it does not do so in schizothoracine fishes. Further, from the anterior face of the lateral process, a small anteriorly directed, conical projection originates both in *Labeo dero* and *Schismatorhynchus nukta*. Such a a process is absent in schizothoracine fishes, This process fortifies the posterior wall of olfactory chamber and therefore, increases the lodging capacity of the bony chamber for the olfactory organs. The lateral process in *Garra lamta* is much more promiment than that of other cyprinine genera described here in. In this species, the anterior projection from the lateral process is much stronger and bigger, thus giving a more firm articulation of the lateral ethmoid with the lacrymal.

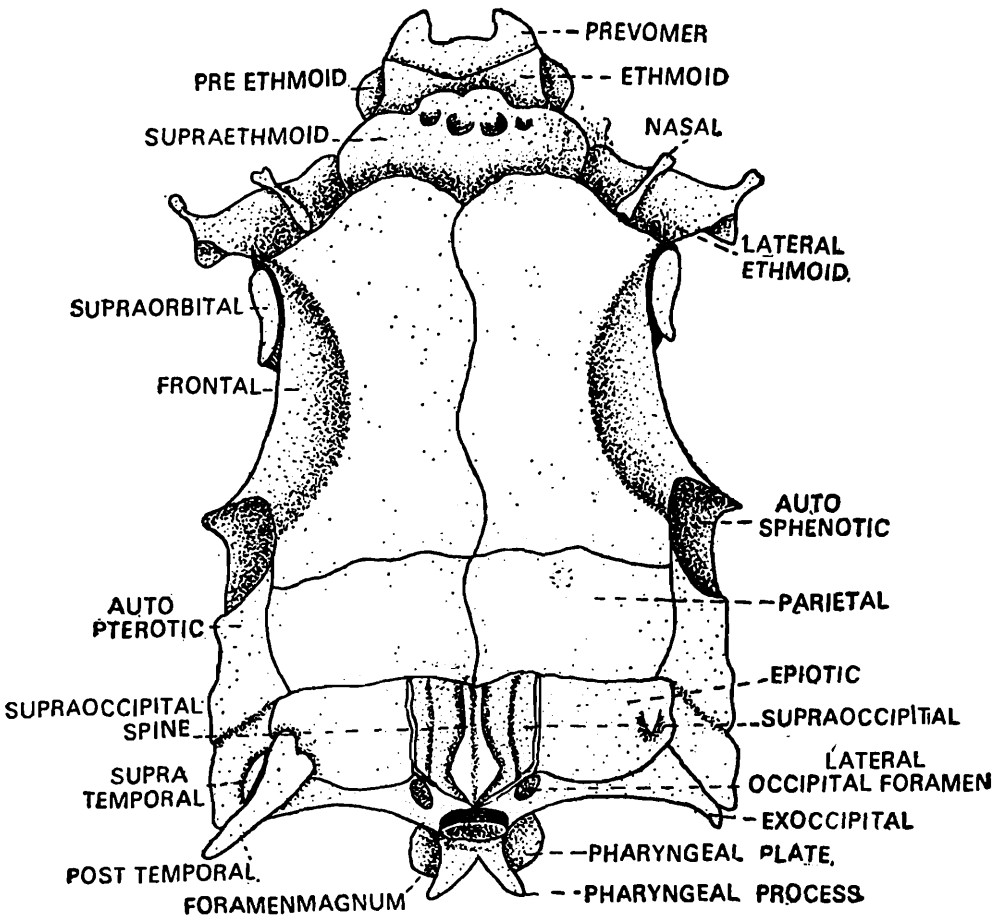

PREVOMER
PRE ETHMOID
ETHMOID
SUPRAETHMOID
NASAL
LATERAL ETHMOID
SUPRAORBITAL
FRONTAL
AUTO SPHENOTIC
PARIETAL
AUTO PTEROTIC
EPIOTIC
SUPRAOCCIPITAL SPINE
SUPRAOCCIPITAL
LATERAL OCCIPITAL FORAMEN
SUPRA TEMPORAL
EXOCCIPITAL
PHARYNGEAL PLATE
POST TEMPORAL
FORAMENMAGNUM
PHARYNGEAL PROCESS
5MM

FIG 9

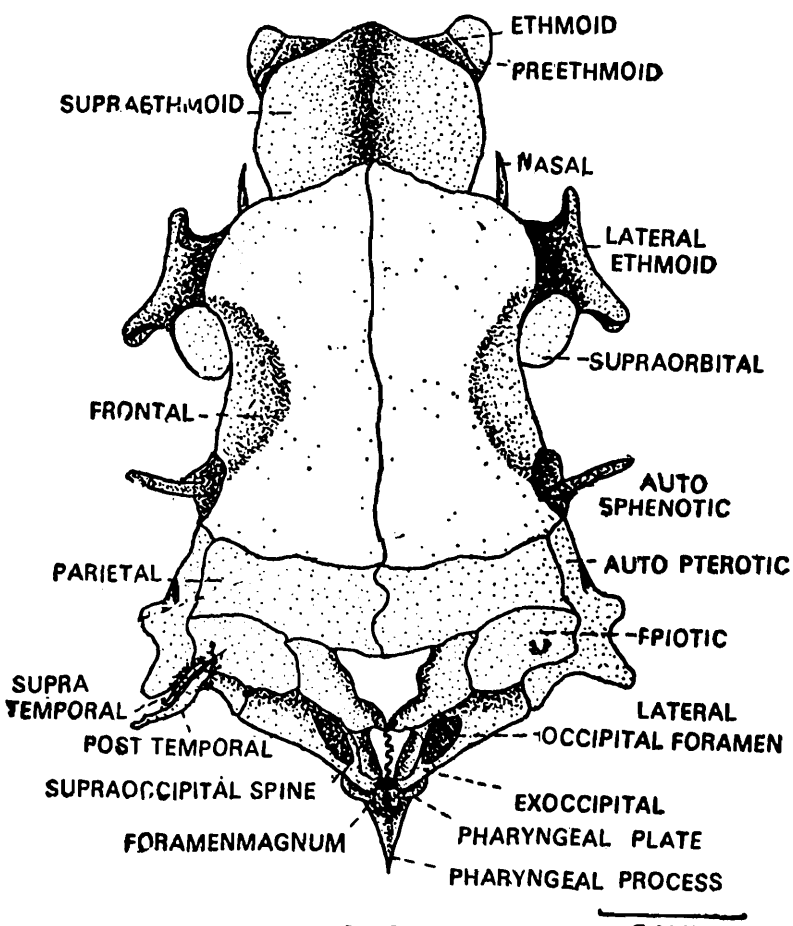

ETHMOID
PREETHMOID
SUPRAETHMOID
NASAL
LATERAL ETHMOID
SUPRAORBITAL
FRONTAL
AUTO SPHENOTIC
AUTO PTEROTIC
PARIETAL
EPIOTIC
SUPRA TEMPORAL
LATERAL OCCIPITAL FORAMEN
POST TEMPORAL
SUPRAOCCIPITAL SPINE
EXOCCIPITAL
FORAMENMAGNUM
PHARYNGEAL PLATE
PHARYNGEAL PROCESS
5 MM

FIG 10

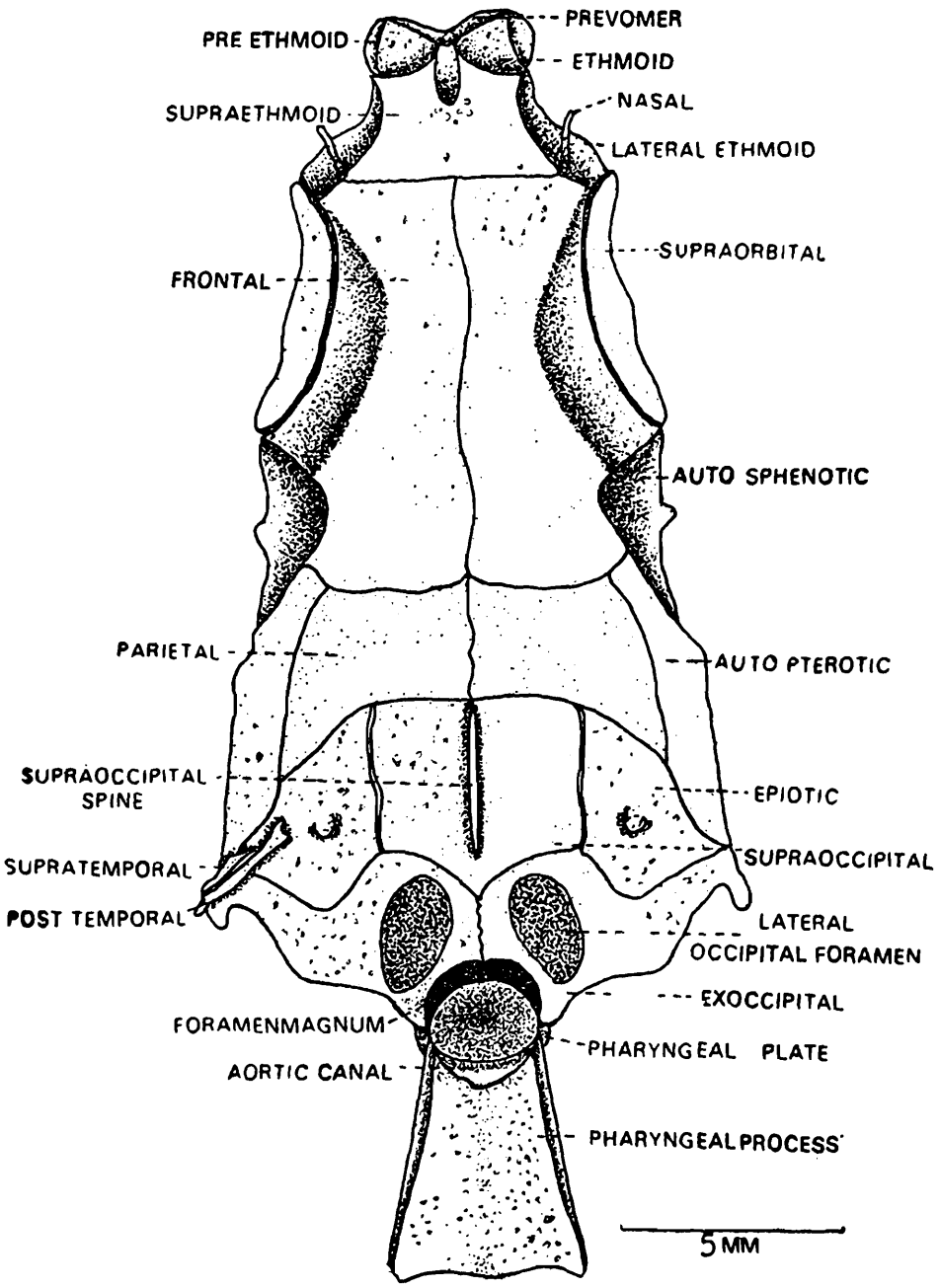


FIG 11

In *Rasbora daniconius*, only a very small part of the lateral process is seen on the dorsal side. The tip of this process is pointed and much smaller than that of all the species studied. In *Aspidoparia morar*, the anterior process of the lateral ethmoid is absent and it no longer takes part in the formation of anterior part of the immensely large orbit.

Preethmoid (Figs. 1-24) : Each preethmoid is a small, nodular bone which fits into a fossa formed partly by the prevomer and partly by the ethmoid. It is firmly fused to its respective receptacle (Harrington, 1955 and Howes, 1978). In *Schizothorax richardsonii*, *Diptychus maculatus*, *Schizopygopsis stoliczkae* and *Rasbora daniconius*, it lies anterolateral to the prevomer and the latter slightly shields it whereas in *Ptycobarbus*

conirostris, *Schizothoraichthys* spp., *Garra lamta* and *Aspidoparia morar*, it occupies somewhat more anterior portion of the prevomer. In *Labeo dero* and *Schismatorhynchus nukta*, it lies posterolateral to the prevomer.

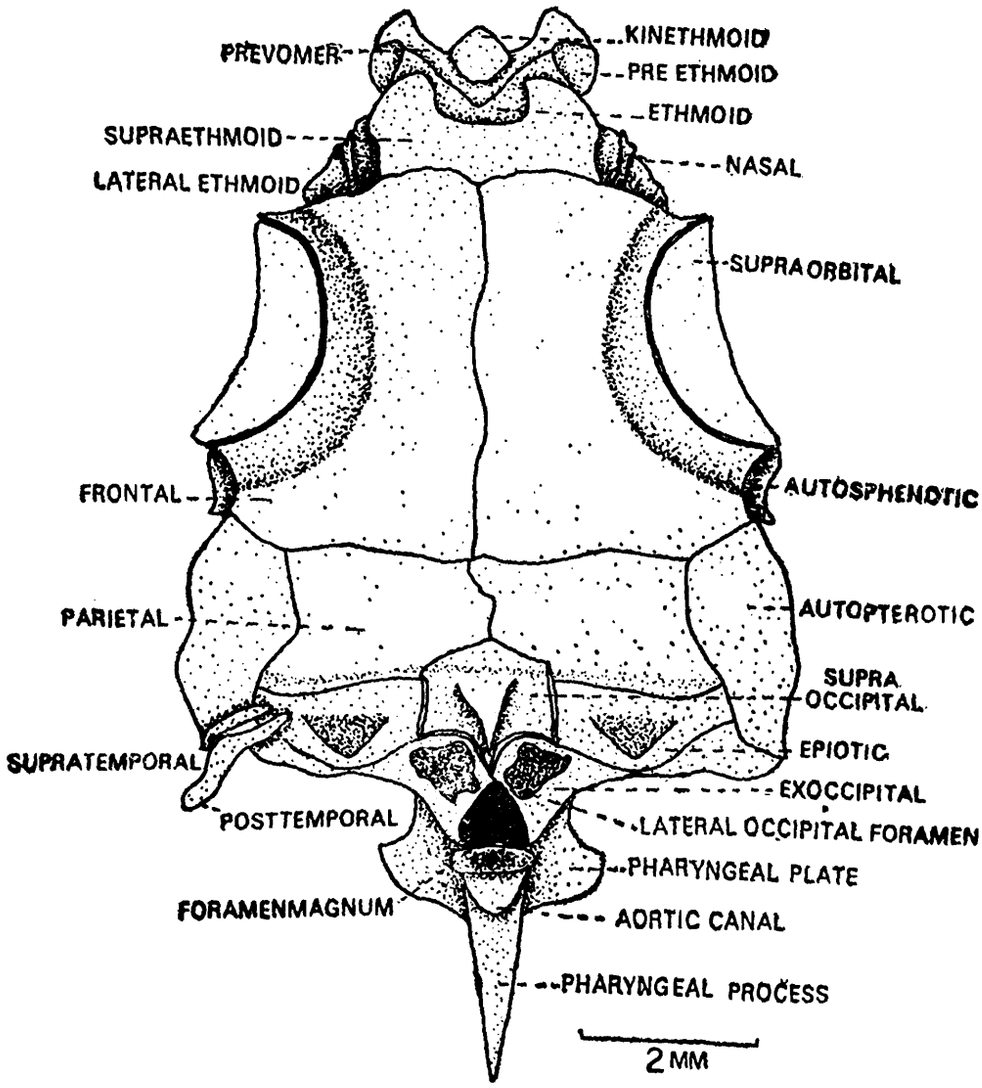


FIG 12

In all the schizothoracine fishes, one pair of preethmoids is present on either side of the prevomer. In *Ptycobarbus conirostris* and *Schizothoraichthys* spp., the pair of preethmoids can easily be recognised by a sutural line of demarcation in between them whereas in rest of the schizothoracine genera under report, the sutural line of demarcation is somewhat obiliterated but can easily be distinguished. In the cyprinine and rasborine genera, only one preethmoid is present on either side of the prevomer. Each preethmoid is covered over by a sheath of cartilage and serves for the attachment of the autopalatine of its side.

II. *Basicranial Region* :

This region comprises the unpaired parasphenoid and the basioccipital.

Parasphenoid (Figs. 13-24) : It is an elongated, rod-like bone which forms the medial ventral part of the cranial cavity and extends between the otic and the orbital regions. Anteriorly, it interdigitates with the

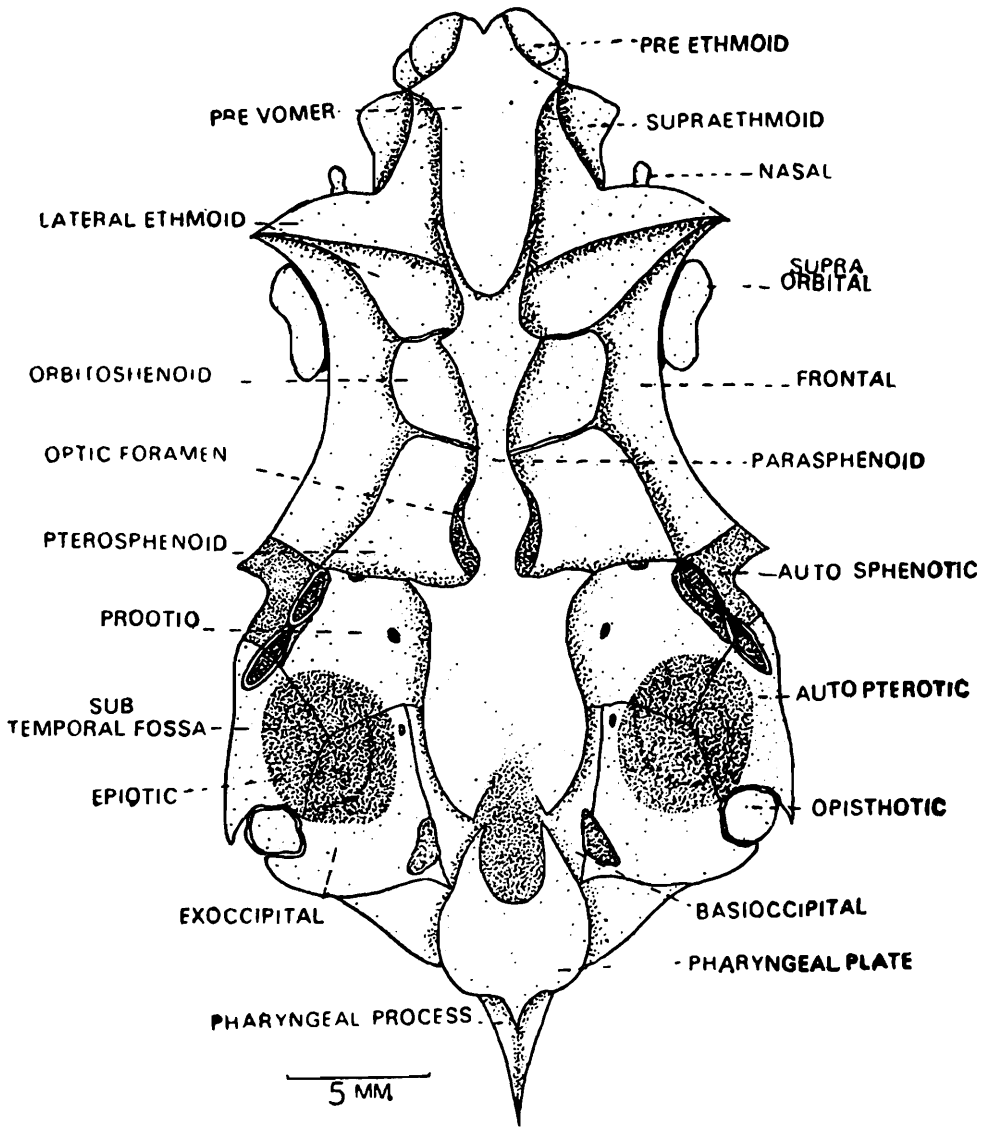


FIG 13

Figs. 13-24. Ventral aspects of skulls (Premaxillaries ; maxillaries, suborbital series ; supratemporals and posttemporals removed) of *Schizothorax richardsonii, Diptychus maculatus, Schizopygopsis stoliczkae, Ptycobarbus conirostris, Schizothoraichthys micropogon, S. esocinus S. labiatus, Labeo dero, Schismatorhynchus nukta, Garra lamta, Aspidoparia morar* and *Rasbora daniconius* respectively.

posterior extremity of the prevomer. On its anterolateral sides, the parasphenoid articulates with the lateral ethmoid. Anterior border of the parasphenoid is broader up to pterosphenoidal region in *Schizothoraichthys esocinus* whereas in all the other schizothoracine genera under report, it is comparatively less broad. The parasphenoid in these fishes

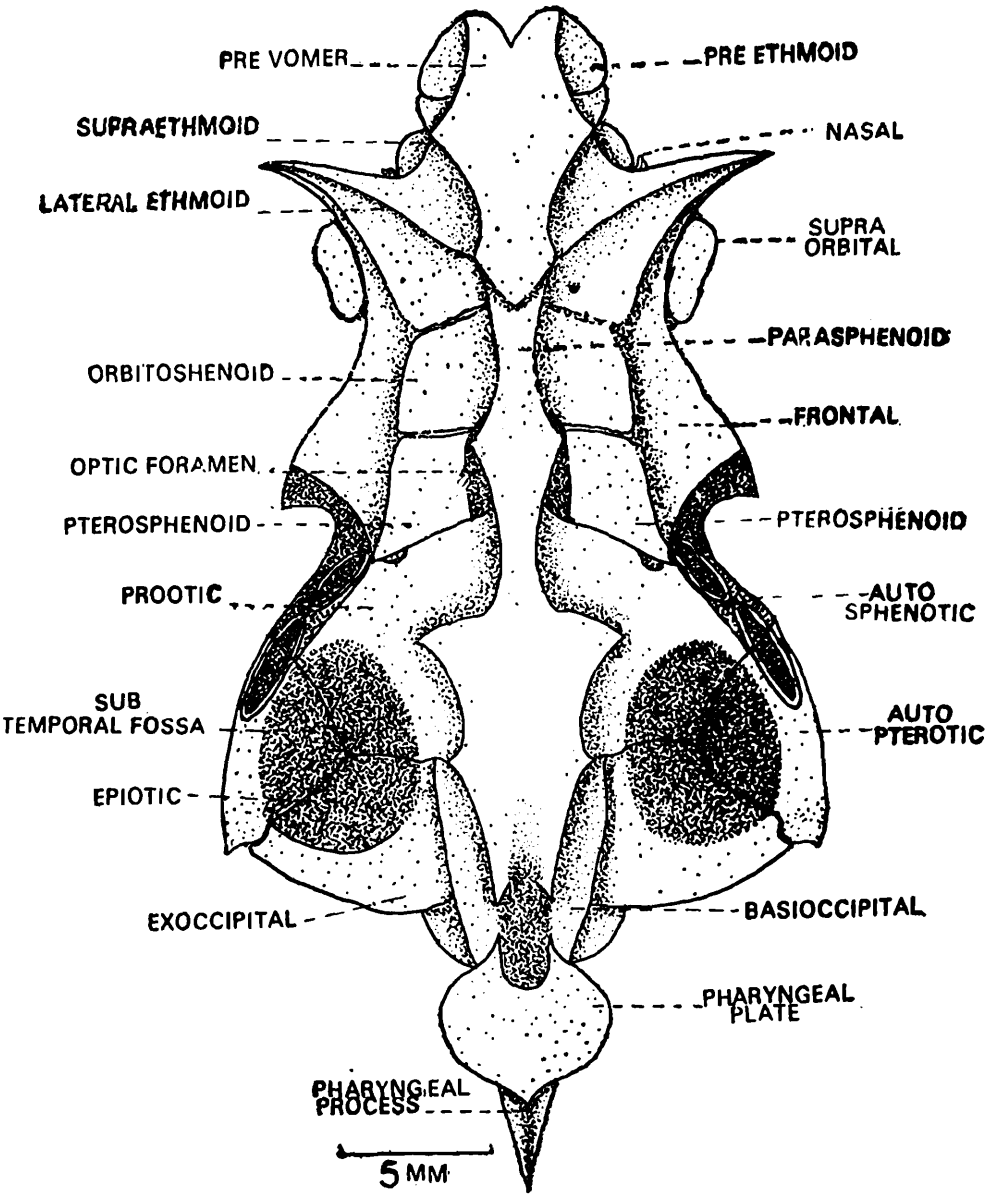


FIG 14

has moved ventrally away from the orbitosphenoid and pterosphenoids ; it retains an articulation with these bones through a thin, bony vertical ridge—the interorbital septum. The latter is very much reduced in *Schizothoraichthys esocinus* as compared to the other schizothoracine genera under report where it is moderately developed. In *Labeo dero* and *Schismatorhynchus nukta*, the parasphenoid is of moderate thickness up to pterosphenoidal region. The interorbital septum is moderately developed and the anterior portion of the parasphenoid forms a mid-ventral keel.

In *Garra lamta*, the anterior tip of the parasphenoid is much broader to match the broad provomer. The middle part of the parasphenoid forms a strong midventral keel. The parasphenoid is much pressed against the orbitosphenoid and the pterosphenoids. The interobital septum is absent,

In *Rasbora daniconius* and *Aspidoparia morar*, the prarasphenoid is an extremely thin, strut-like bone up to the pterosphenoidal region. The anterior proecess of the parasphenoid is connected to the orbitosphenoid through a mid-ventral thin sheet of bone acting as an interobital septum. Thus, the latter is incomplete in these two genera. The orbitosphenoid, pterosphenoids and the parasphenoid together form interorbital septum in rest of the species studied.

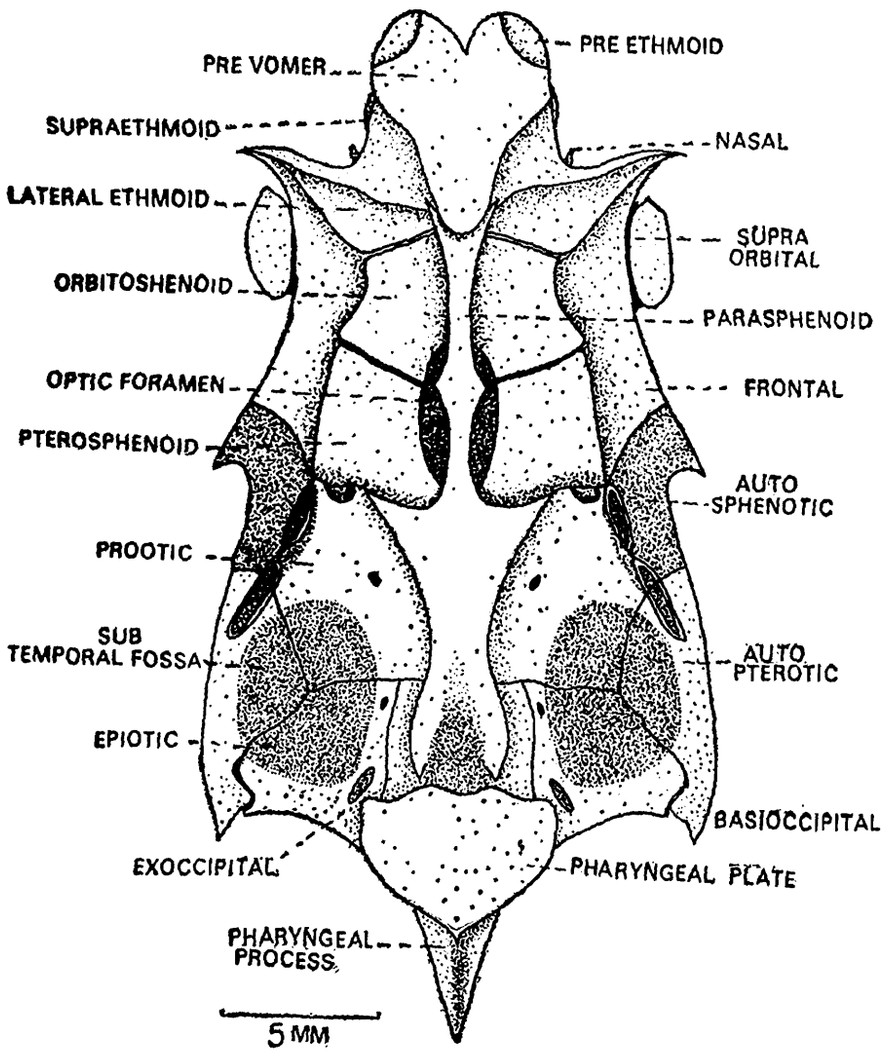


FIG 15

Basioccipital (Figs. 13-36) : It is large bone, thick in the middle and narrow at both the ends. It forms the floor and side walls of cavum sinus imparis. The posterior face of the basioccipital is concave and represents the fused centrum of the proatlas vertebra (Wiesel, 1972). At this point, the vertebral column is firmly fused to the neurocranium. Anterolaterally, the basioccipital is covered by the basal portion of the prootics. Laterally, it articulates with the exoccipitals. Anteriorly,

the basioccipital is produced into a wing-like extension which forms a masticatory plate. The latter serves as a grinding surface for the pharyngeal teeth. The shape and size of the plate is different in different species. In *Schizopygopsis stoliczkae*, *Diptychus maculatus*, *Labeo dero* and *Schismatorhynchus nukta*, it is a broad, wing-like structure while it is comparatively less developed in rest of the species under report.

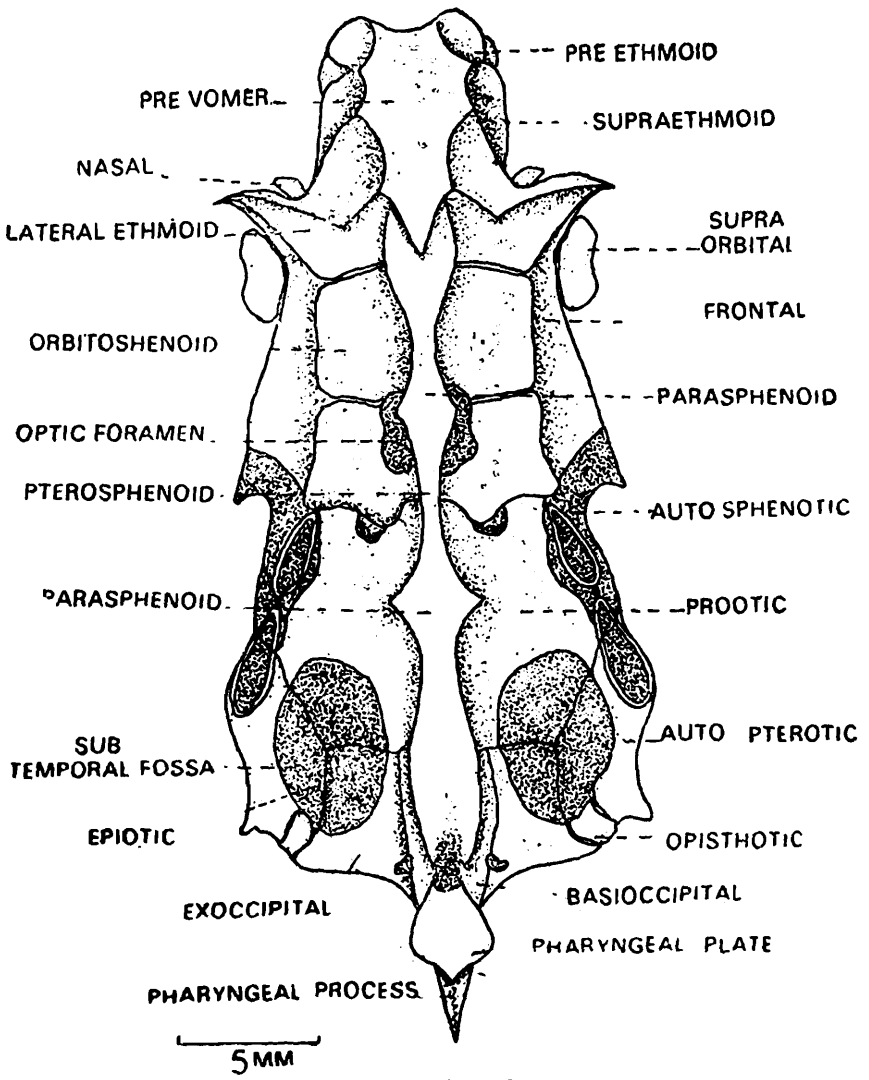


FIG 16

The plate is very much reduced in *Garra lamta*. Posteriorly, the basioccipital is produced into a pharyngeal process which is long, pointed and spine-iike in all schizothoracine genera, *Rasbora daniconius* and *Garra lamta*. In latter case, the spine is slightly reduced. In *Labeo dero* and *Schismatorhynchus nukta*, posterior tip of the pharyngeal process is bifid while in *Aspidoparia morar*, it is deeply square-cut and the process has lateral extensions.

III. *Orbital Region* :

This region lies posterior to the olfactory region and comprises the largest part of the neurocranium. It includes the median unpaired orbitosphenoid and paired pterosphenoids, paired lacrymals, suborbitals and the frontals. The orbits are large in size and lie in the anterior half of the neurocranium in dorsolateral aspect and occupy $\frac{1}{3}$rd of its length.

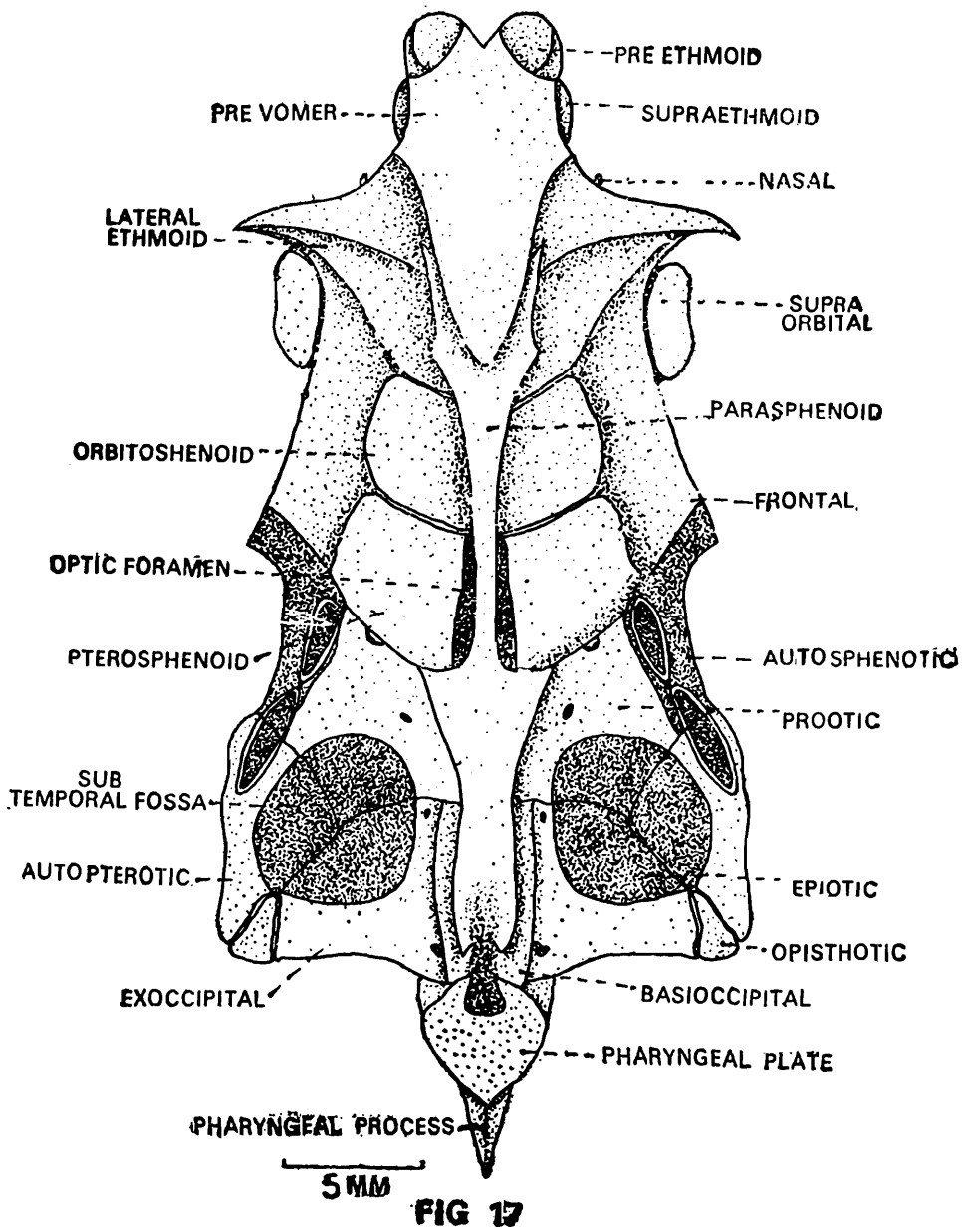


FIG 17

Orbitosphenoid (Figs. 13-24) : It is a greatly depressed bone which is sandwiched between the frontals and the parasphenoid. Anteriorly, this bone articulates with the lateral ethmoids and posteriorly, to the anterior borders of the pterosphenoids. It bears a groove on its ventral surface into which fits the stem of the parasphenoid posterioly.

It contributes to the formation of the floor and inner walls of the orbit and olfactory tract. In *Schizothorax richardsonii*, *Schizothoraichthys esocinus*, *Ptycobarbus conirostris* and *Garra lamta*, the *orbito*-sphenoid does not take part in the formation of optic foramen while it takes a small part in the formation of anterior part of the optic foramen in *Diptychus maculatus*, *Schizothoraichthys micropogon* and *Schizothoraichthys labiatus*. In rest of the species under report, the orbitosphenoid takes 1/3rd part in the formation of optic foramen.

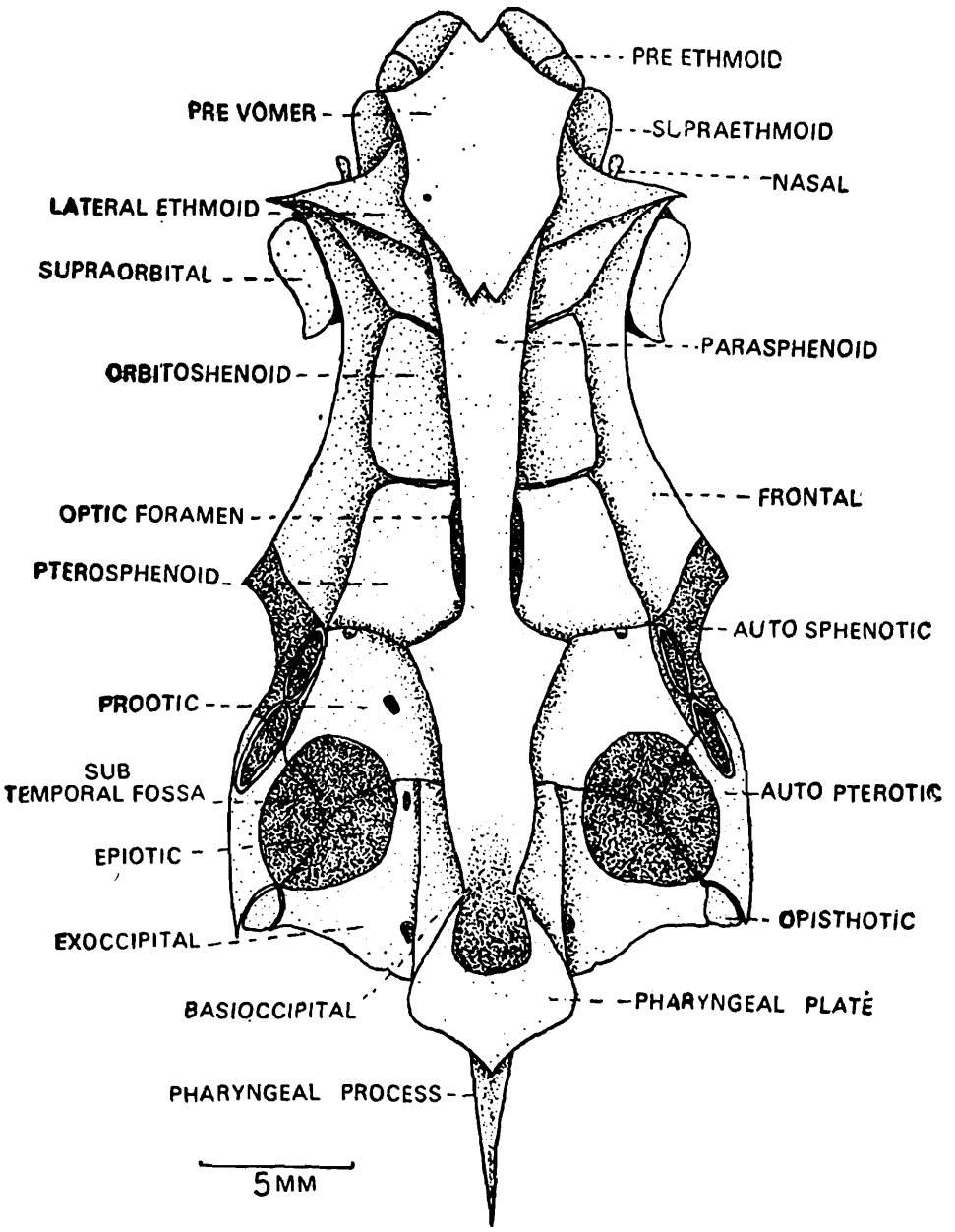


FIG 18

Pterosphenoid (Figs. 13-24) : Each pterosphenoid is a hexagonal plate lying one on either side of the parasphenoid just posterior to the orbitosphenoid. It forms sutural joints with the orbitosphenoid

anteriorly, prootic posteriorly, autosphenotic dorsoposteriorly, frontal dorsally and parasphenoid ventrally. No marked differences are seen in the shape of pterosphenoid.

Suborbital series (Figs. 37-48) : There are five curved suborbital bones, forming the anterior, ventral and posterior boundary of the orbit on either side ; through them passes the suborbital trunk of the sensory canal which continues posteriorly into the autosphenotic.

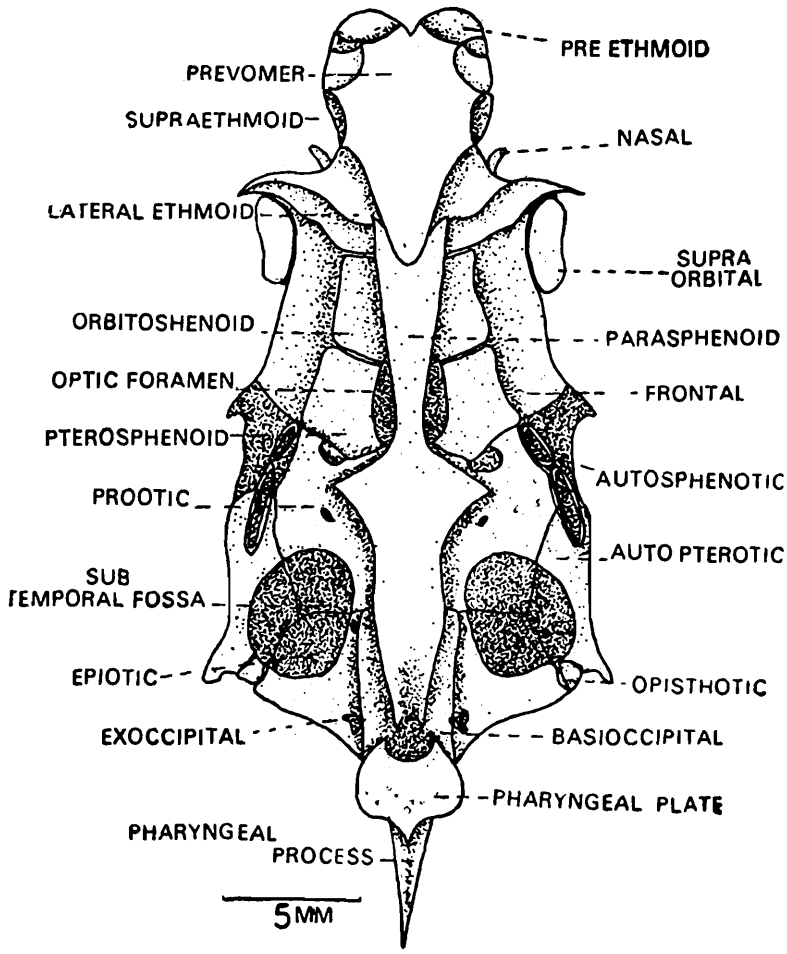


FIG 19

(i) *Lacrymal* (Suborbital I) (Figs. 37-48) : It is the anteriormost bone amongst all suborbitals. In all the schizothoracine genera and *Garra lamta*, it is the largest bone of the series. In *Labeo dero* and *Schismatorhynchus nukta*, each lacrymal equals in length to the second suborbital while it is smaller than the second suborbital in *Rasbora daniconius* and *Aspidoparia morar*.

(ii) *Suborbitals* (2-5) (Figs. 37-48) : In *Schizopygopsis stoliczkae*, *Diptychus maculatus*, *Schizothoraichthys labiatus* and *Schizothoraichthys micropogon*, fourth suborbital is the smallest, whereas fifth is the smallest

in *Ptycobarbus conirostris*, *Schizothorax richardsonii*, *Schizothoraichthys esocinus* and the cyprinine genera under report. In *Rasbora daniconius* and *Aspidoparia morar*, the fifth suborbital is wide but reduced in length and the third is the largest.

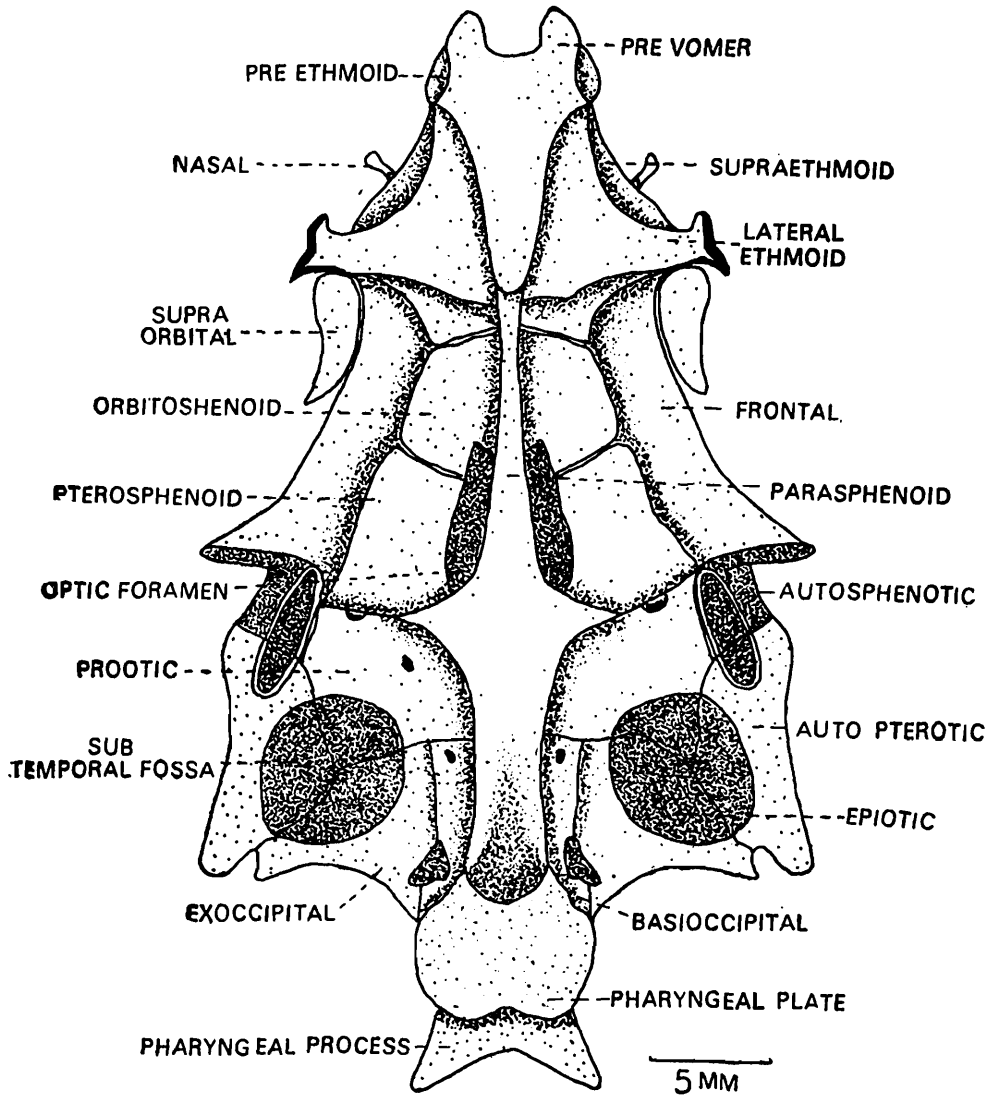


FIG 20

Supraorbital (Figs. 1-24) : It is a small bone attached to the anterolateral margin of the frontal on either side. It is a flattened, oval bone in schizothoracine fishes and *Garra lamta* and covers a small dorsal part of the orbit. In *Labeo dero* and *Schismatorhynchus nukta*, it is slightly enlarged and covers almost half of the dorsal part of the orbit. The supraorbital in *Rasbora daniconius* and *Aspidoparia morar* is very prominent, elongated and forms almost whole of the dorsal border of the orbit. The frontals are, thus, excluded fully from the orbital part.

Frontal (Figs 1-12) : Each frontal is a large flat bone arranged on either side of the middorsal line of the neurocranium. They are sutu-

rally united with supraethmoid on the anterior side, parietals on posterior side and the autopterotics and autosphenotics on the posterolateral sides. Anterolaterally, each frontal slopes down gradually and articulates with the lateral ethmoid and the nasal. The frontal lodges a part of the supraorbital sensory canal. The lateral border of the frontal forms the dorsal boundary of the orbit. The fontanellae of the frontals are wanting in these fishes.

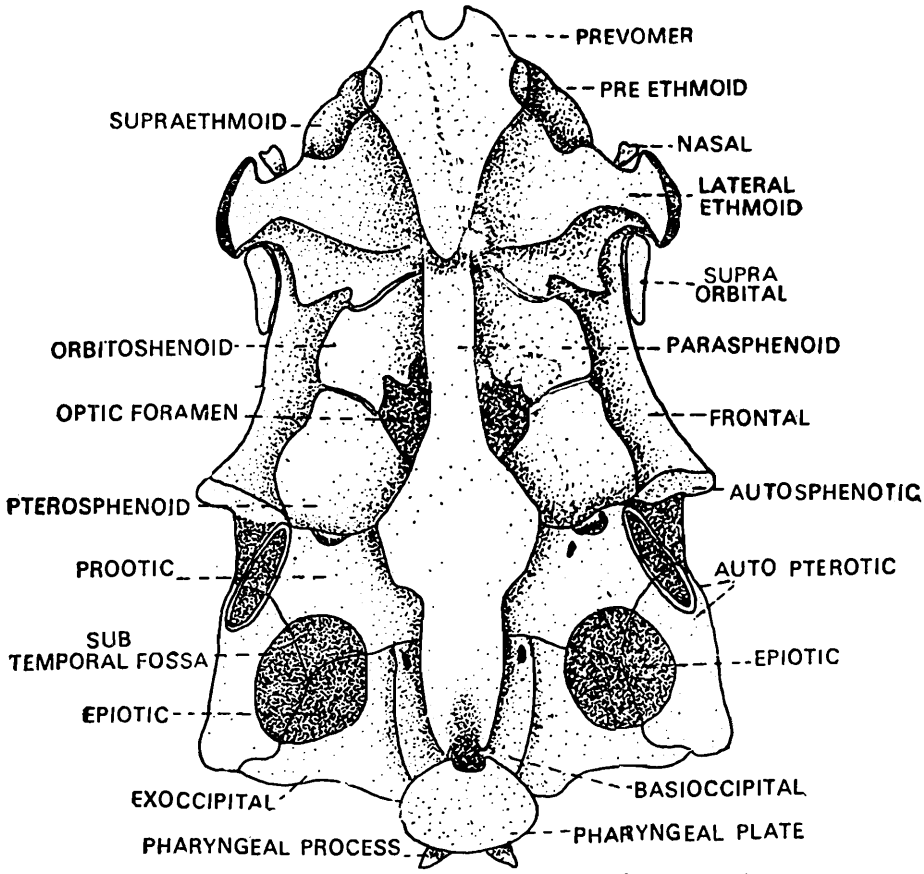


FIG 21

In *Labeo dero*, *Schismatorhynchus nukta* and *Rasbora daniconius*, each frontal is wider than that of schizothoracine genera and *Aspidoparia morar*. As frontal is a wide bone, the total width of the roof of the skull is also more than that of schizothoracine genera. In *Schismatorhynchus nukta*, the frontals take part in snout formation. In *Garra lamta*, each frontal is broad anteriorly, particularly at the frontosupraethmoidal articulation.

IV. *Otic Region* :

The otic region comprises a median unpaired supraoccipital, paired exoccipitals, the autopterotics, the autosphenotics, the prootics, the

epiotics, the opisthotics, the parietals, the posttemporals and the supratemporals.

Supraoccipital (Figs. 1-12 and 25-36) : Together with the epiotics, it forms the posterior region of the neurocranium and is a pentagonal structure. In *Schizothorax richardsonii*, *Diptychus maculatus*, *Ptycobarbus conirostris*, *Labeo dero*, *Schismatorhynchus nukta* and *Rasbora daniconius*,

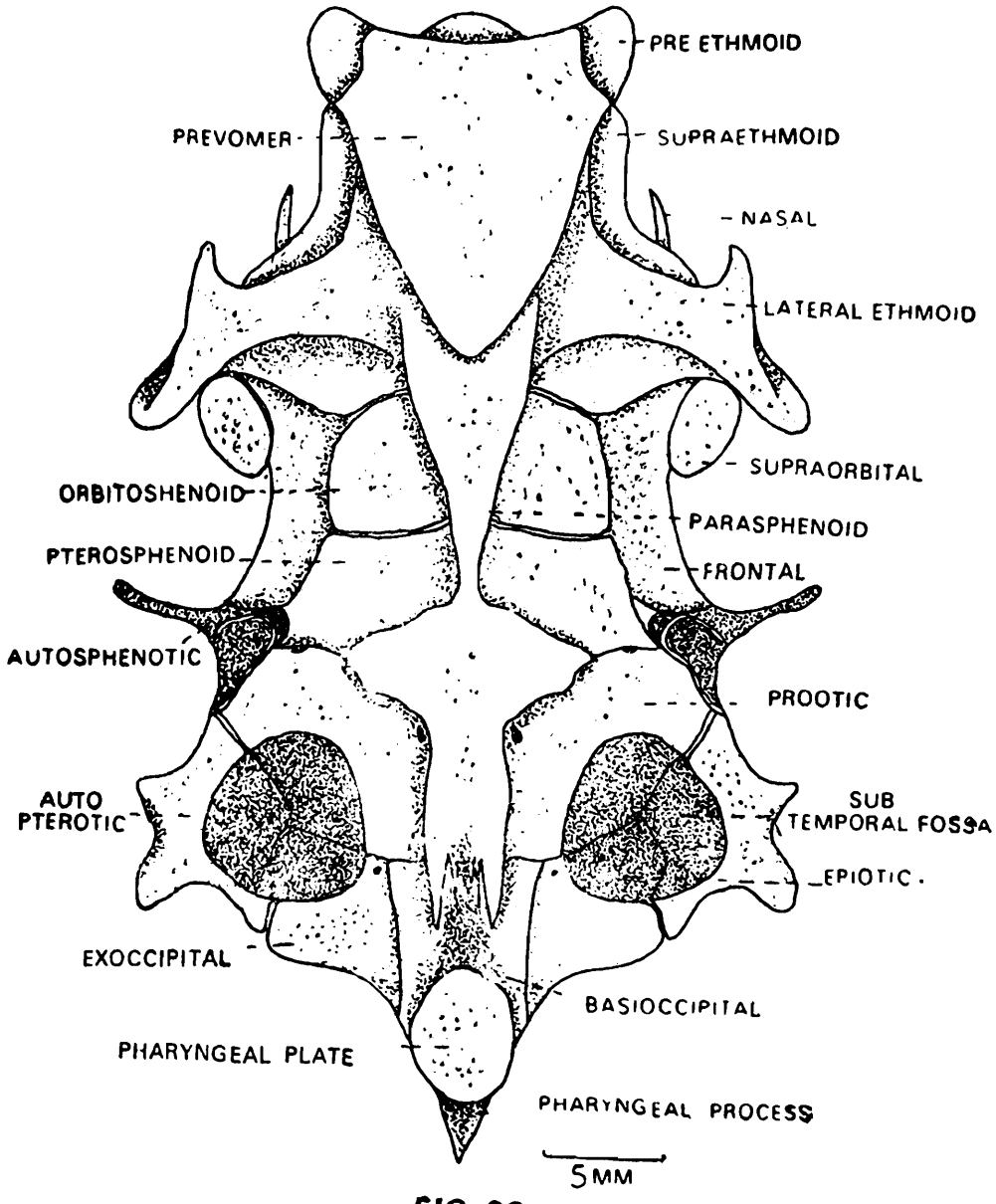


FIG 22

its posterior limit falls a little short of the foramen magnum whereas in *Schizopygopsis stoliczkae*, *Schizothoraichthys spp.*, *Garra lamta* and *Aspidoparia morar*, it falls far short of the foramen magnum. In *Schizothoraichthys micropogon* and *Schizothoraichthys labiatus*, it does not even extend beyond the epiotics. Hence, it does not take part in the formation of the foramen magnum.

From the dorsomedian surface of the supraoccipital arises a wing-like process— the supraoccipital spine— which projects dorsally. The extent of this spine differs in different species. The spine is high in *Schizothorax richardsonii* and *Schizothoraichthys esocinus* than in other

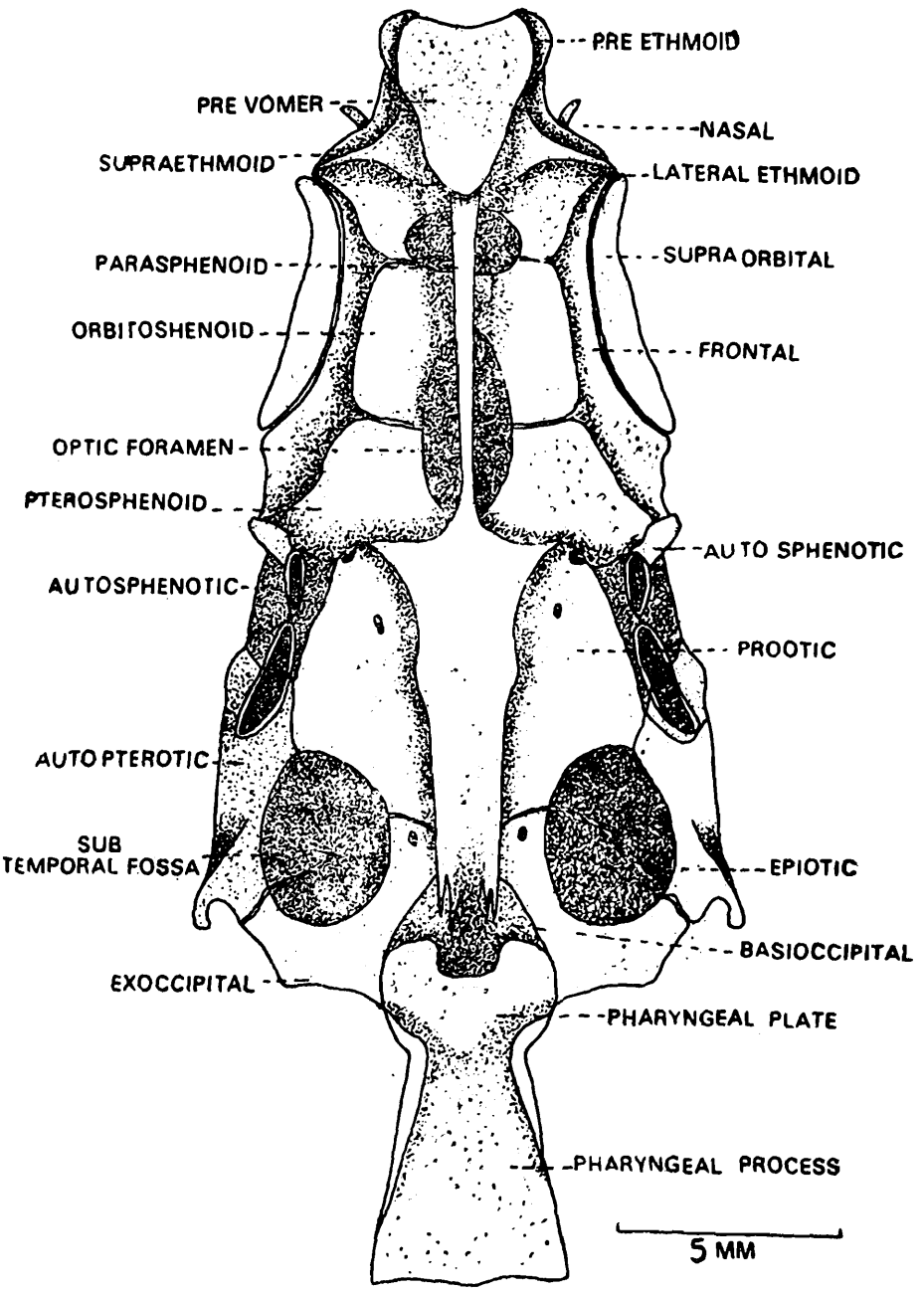


FIG 23

schizothoracine genera. In *Labeo dero* and *Schismatorhynchus nukta*, it forms an expanded plate along its dorsal edge which is pitted dorsally and is a double ridged structure, one superimposed upon the other. In *Garra lamta*, the spine arises as two vertical ridges, one on either side of the middorsal line.

The supraoccipital articulates anteriorly with the parietals, laterally to the epiotics and posteriorly to the exoccipitals.

Exoccipital (Figs. 1-36) : Each exoccipital is a large and extensive bone consisting of : (i) a basal plate forming part of the posterior portion of the floor of the cranial cavity (ii) a large, winged lateral paroccipital process which forms the side walls of the cranial cavity and posterior boundary of the auditory capsule (iii) a small dorsal process which encloses half of the foramen magnum of its side.

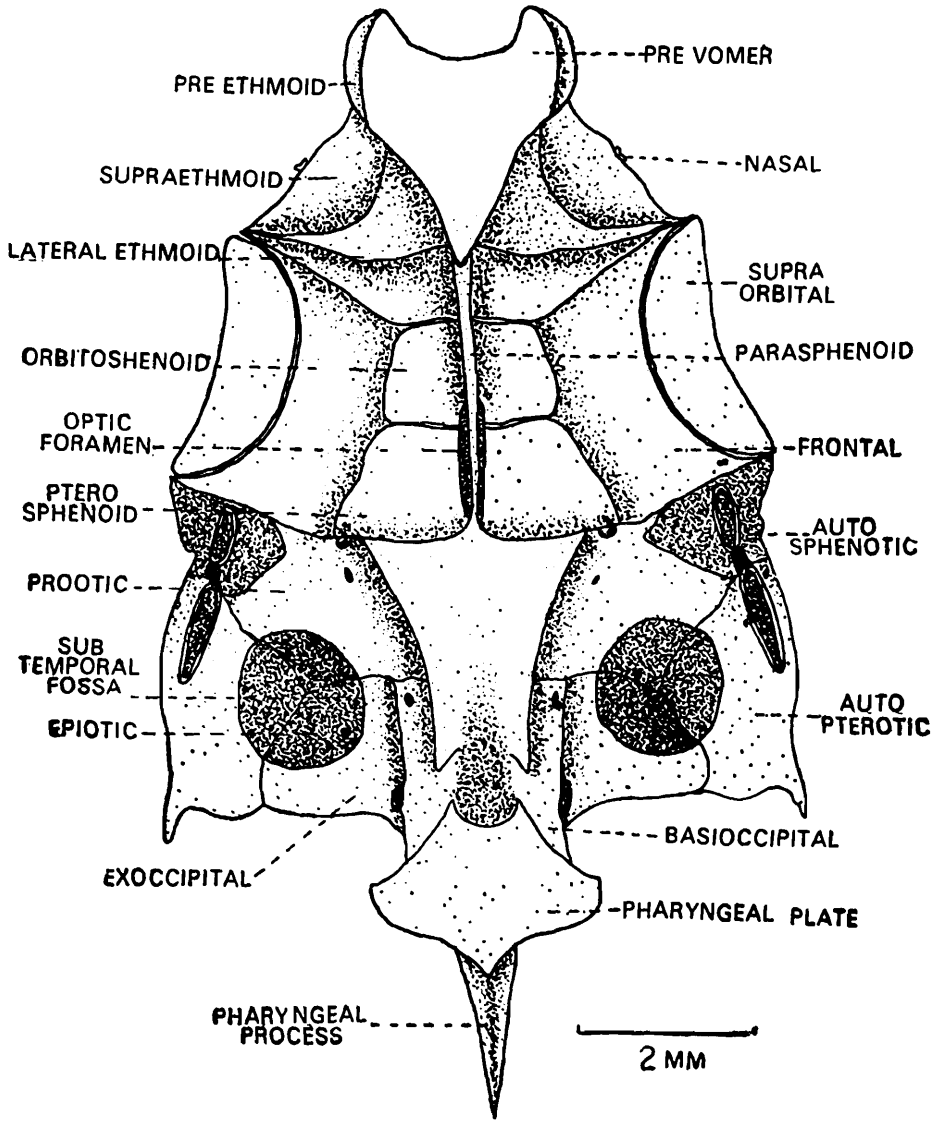


FIG 24

The basal plate of each exoccipital is a flat bony piece which meets the corresponding plate of the other side in the midventral line and forms the hinder portion of the cranial cavity. The basal plates of the two sides are ventrally united to the basioccipital. From the middle of each exoccipital, a plate-like process arises which runs medially to meet its counter part from the other side, thus forming a flat, horizontal

plate. The latter acts as a base for the posterior part of the cranial cavity. Thus the foramen magnum gets completely enclosed by the exoccipitals alone, with the horizontal plate of the exoccipitals at the

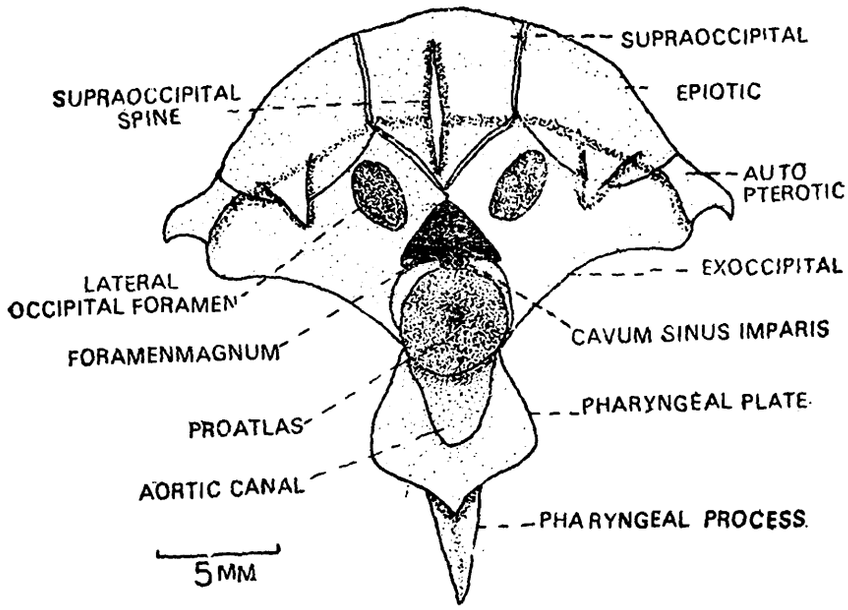


FIG 25

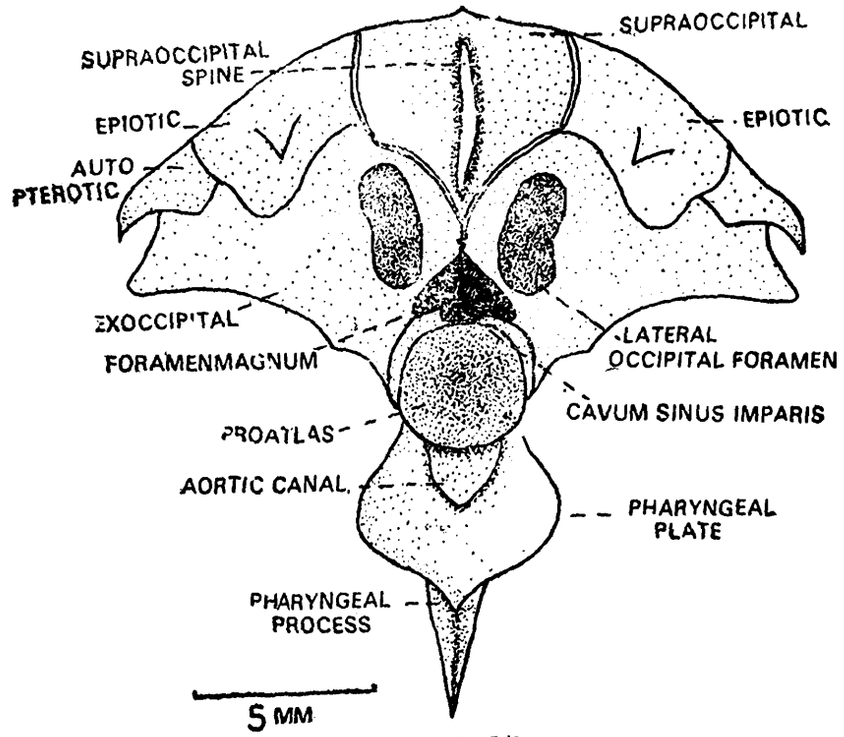


FIG 26

Figs. 25-36. Posterior views of skulls of *Schizothorax richardsonii*, *Diptychus maculatus*, *Schizopygopsis stoliczkae*, *Ptycobarbus conirostris*, *Schizothoraichthys micropogon*, *S. esocinus*, *S. labiatus*, *Labeo dero*, *Schismatorhynchus nukta*, *Garra lamta*, *Aspidoparia morar* and *Rasbora daniconius* respectively.

base and the dorsal sutural union of exoccipitals above. The horizontal plate separates this posterior cranial cavity and the cavum sinus imparis.

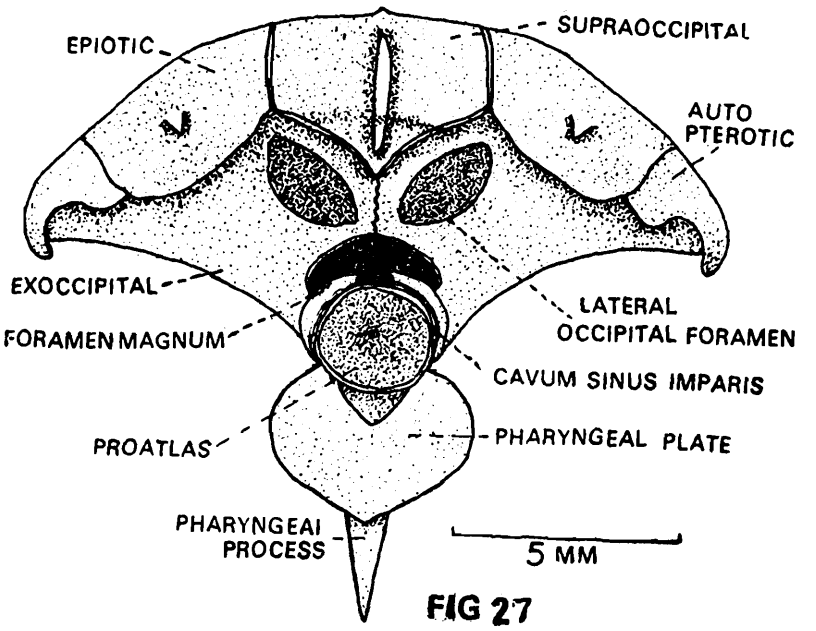


FIG 27

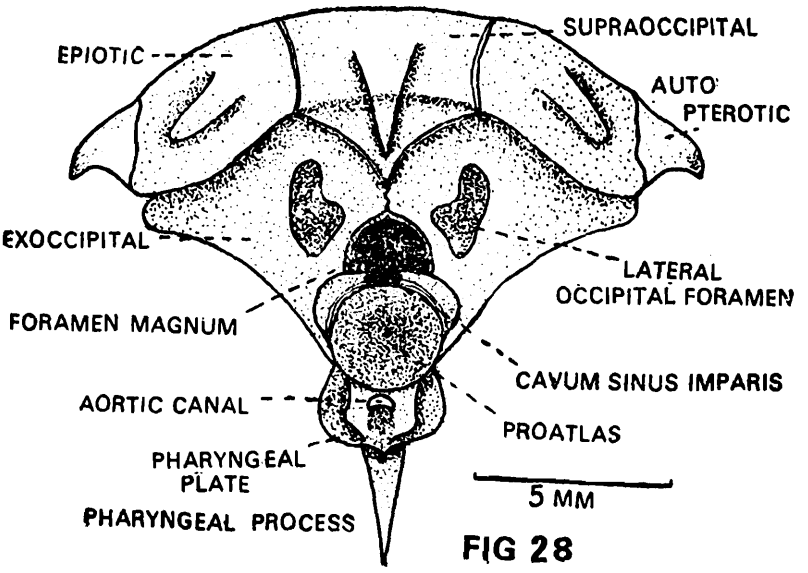


FIG 28

A part of the inner posterior wall of the auditory space is formed by the exoccipitals. Each paroccipital process of the exoccipital is suturally connected laterally to the descending limb of the autopterotic, dorsally to the epiotic and ventrally to the prootic. At the point of union of the exoccipital, the autopterotic and the epiotic, a deep subtemporal fossa is formed on the ventral aspect of the neurocranium.

Autopterotic (Figs. 1-36) : Each autopterotic is a large bone, roughly quadrangular in appearance. Anteriorly, it articulates with the prootic

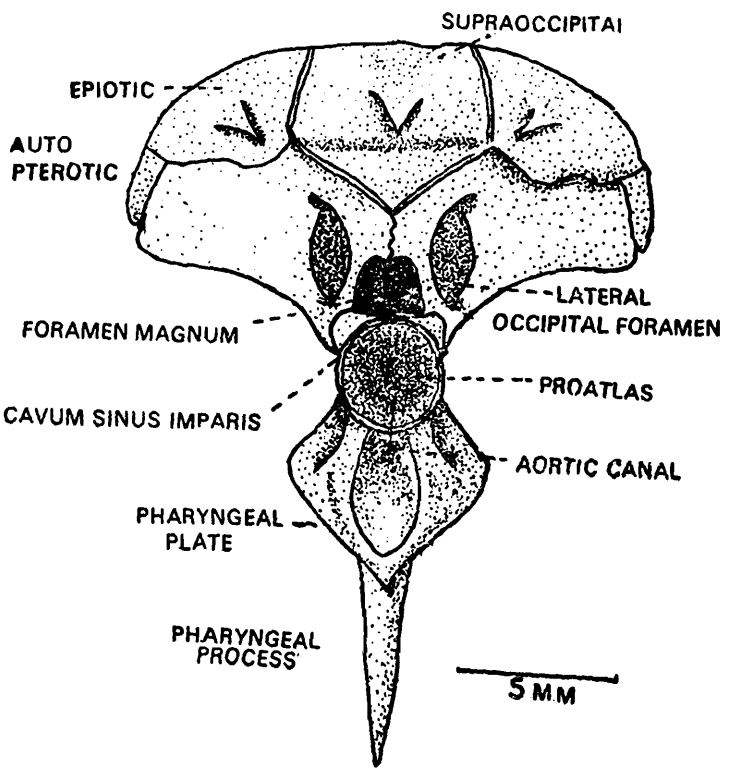

SUPRAOCCIPITAL
EPIOTIC
AUTO
PTEROTIC
LATERAL
OCCIPITAL FORAMEN
FORAMEN MAGNUM
PROATLAS
CAVUM SINUS IMPARIS
AORTIC CANAL
PHARYNGEAL
PLATE
PHARYNGEAL
PROCESS
5 MM

FIG 29

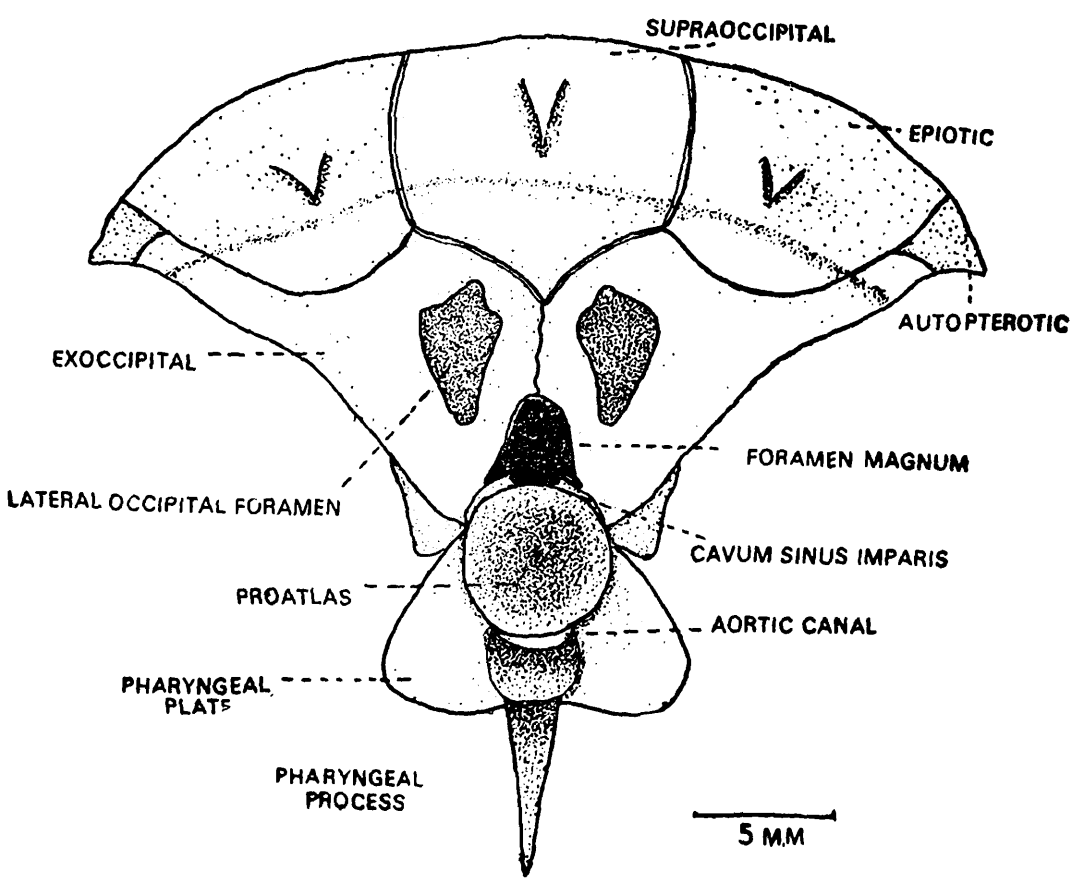

SUPRAOCCIPITAL
EPIOTIC
AUTOPTEROTIC
EXOCCIPITAL
FORAMEN MAGNUM
LATERAL OCCIPITAL FORAMEN
CAVUM SINUS IMPARIS
PROATLAS
AORTIC CANAL
PHARYNGEAL
PLATE
PHARYNGEAL
PROCESS
5 MM

FIG 30

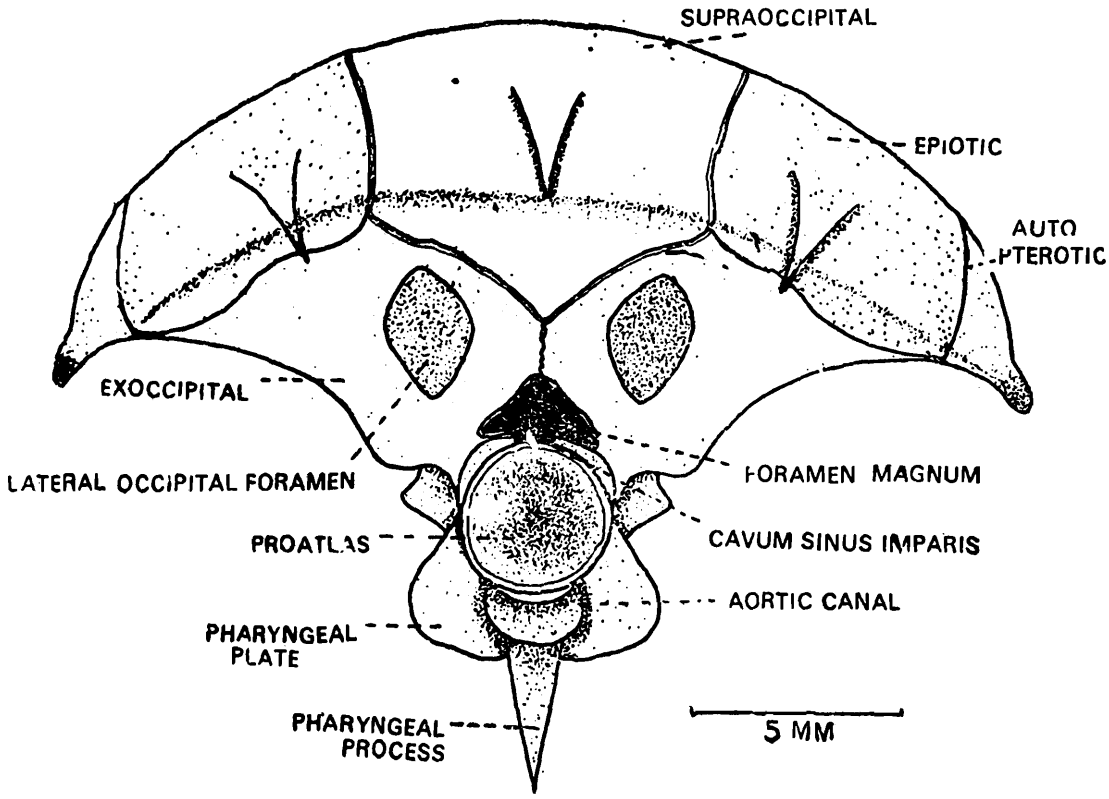


FIG 31

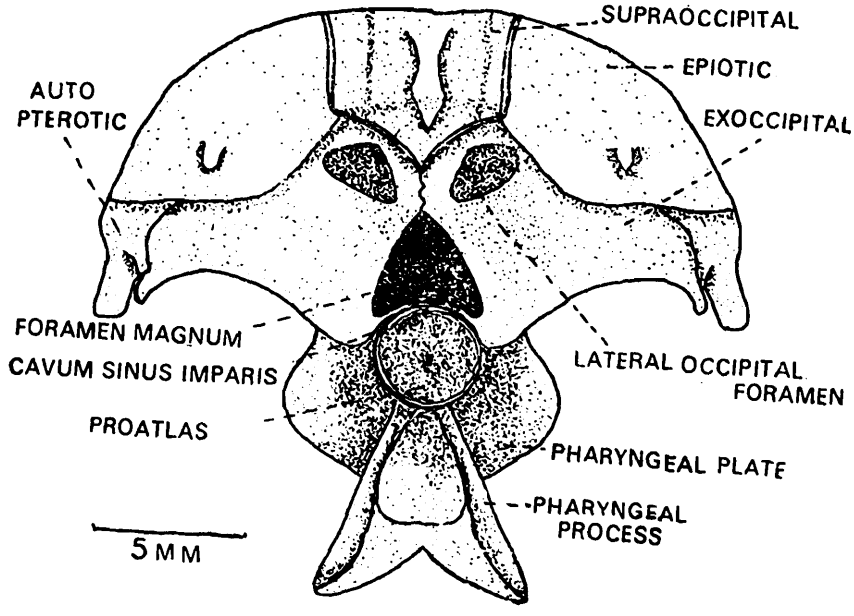


FIG 32

and autosphenotic and posteriorly, with epiotic and paroccipital process of exoccipital. The dorsal part of each autopterotic contributes to the formation of the lateral aspect of the roof of the cranium while the ventral aspect takes part in the formation of the subtemporal fossa. Its outer edge is connected with the upper border of the opercula. bone by means of strong ligaments. On its ventral side, there is a well

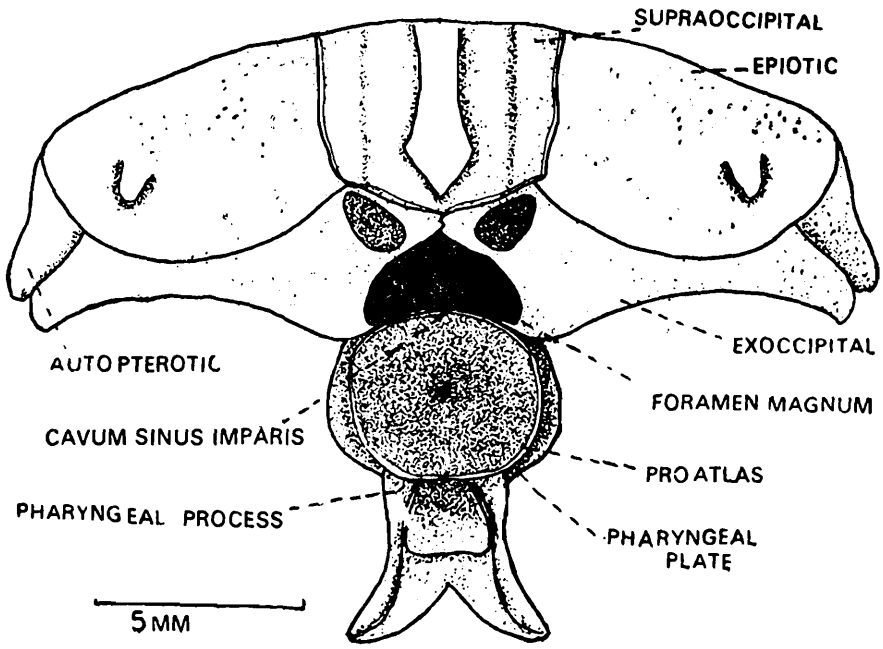


FIG 33

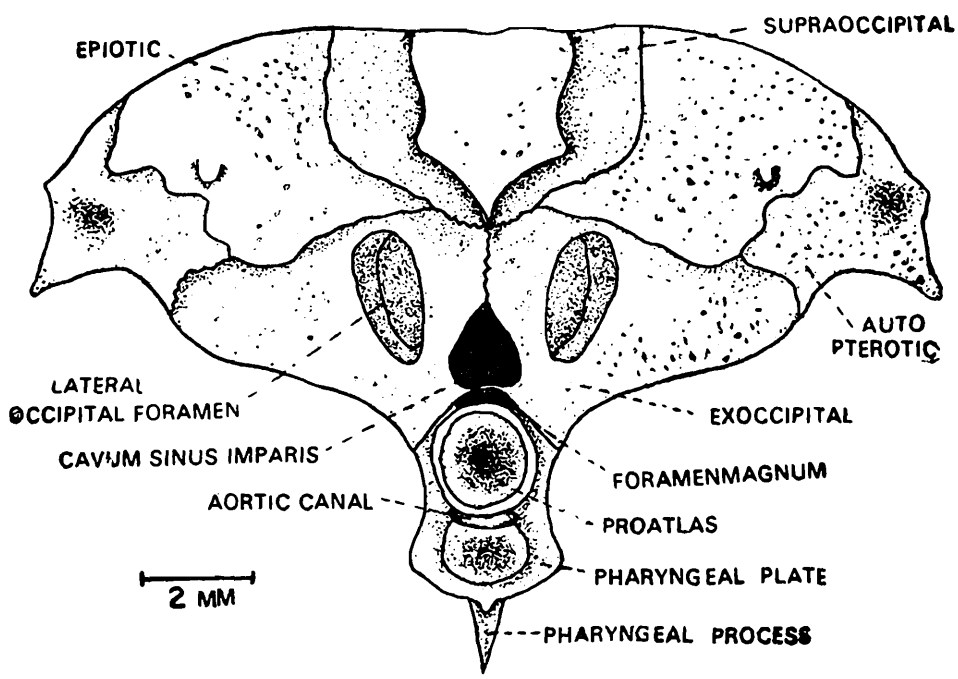


FIG 34

developed, shallow articular facet for the attachment of posterior head of hyomandibular.

In schizothoracine fishes, each autopterotic lies on the outer side of parietal and extends beyond it. It separates the autosphenotic and the parietal. However, in *Ptycobarbus conirostris*, the autopterotic does not touch the frontal and falls slightly short of it. In the cyprinine

genera under report, each autopterotic is reduced in length while in the rasborine genera, it is almost equal to the parietal length but is much smaller in width.

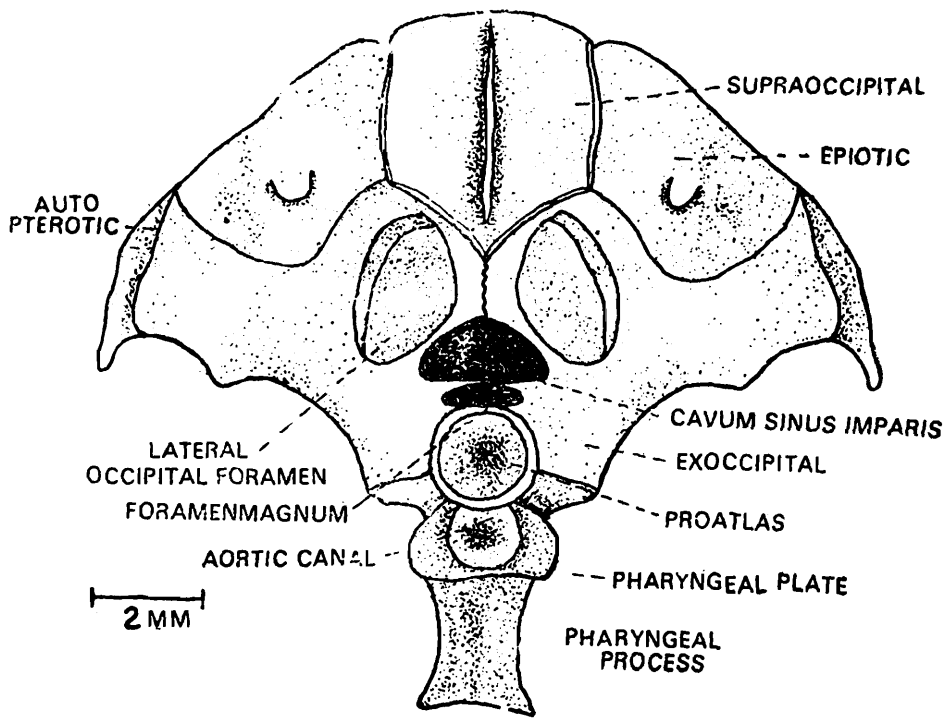


FIG 35

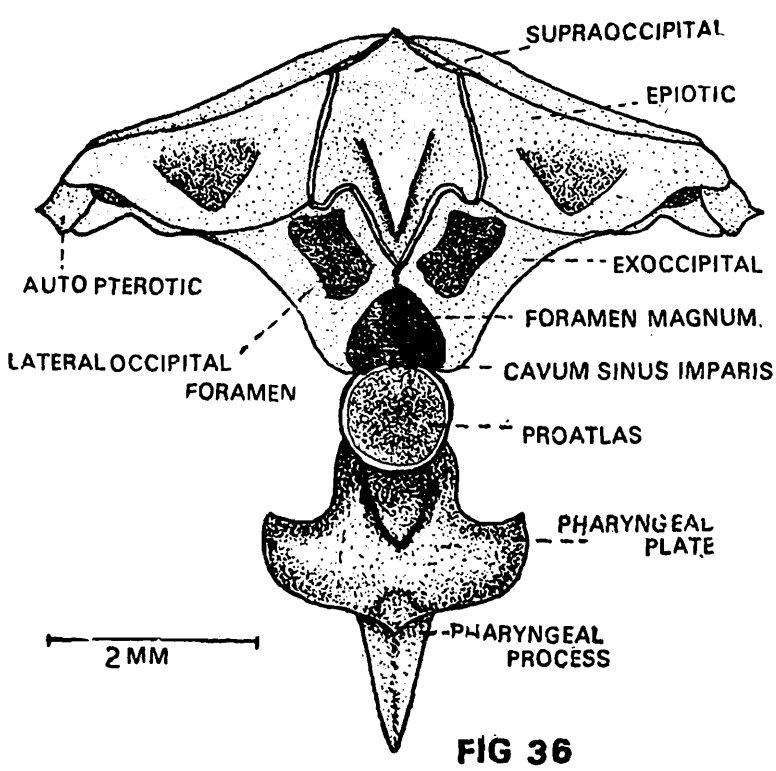


FIG 36

Autosphenotic (Figs. 1-24): It is the anteriormost bone of the auditory capsule and forms the posterior boundary of the orbit. Its dorsal border is covered anteriorly by the frontal but does not come in

contact with the parietal because of the intervention of the autopterotic in all the fishes studied except in *Ptycobarbus conirostris*. The upper end of the fifth suborbital is connected through ligaments to the upper surface of the autosphentic. This bone forms a sutural joint anteriorly with the pterosphenoid, dorsally with the prootic and posteriorly with

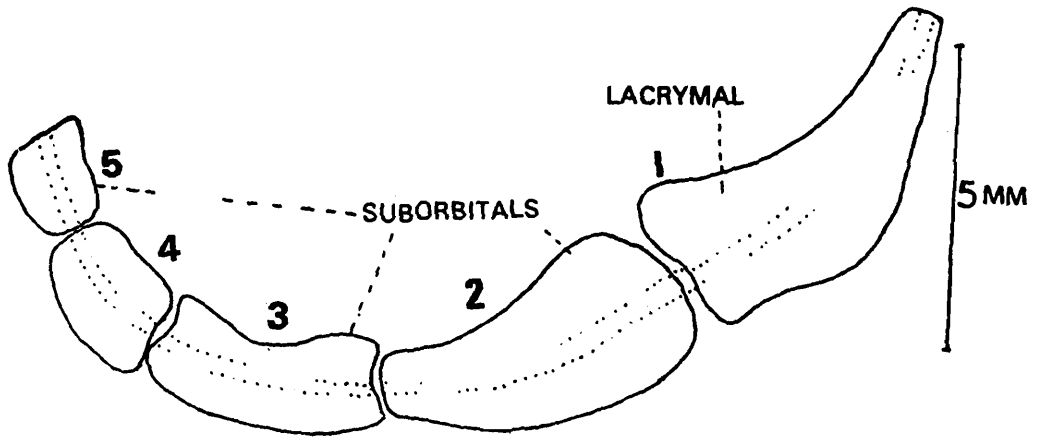


FIG 37

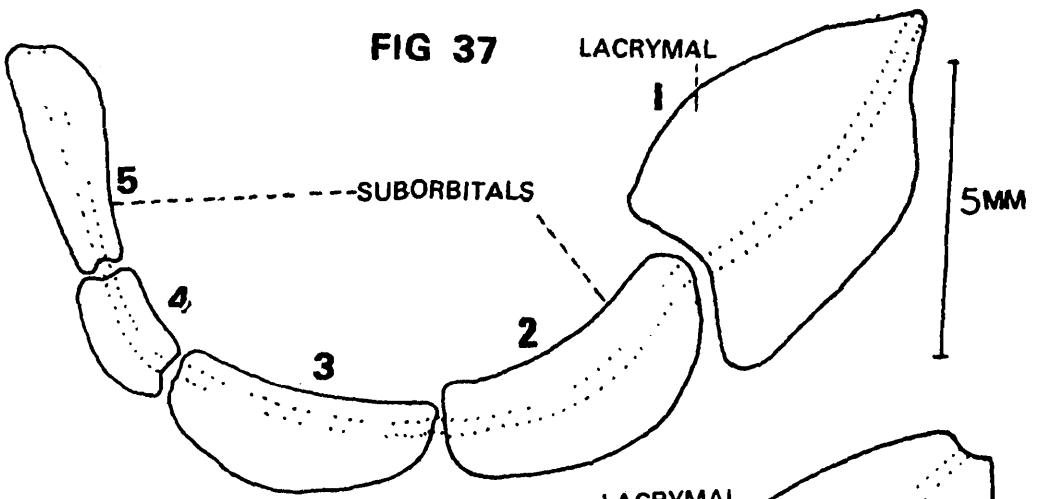


FIG 38

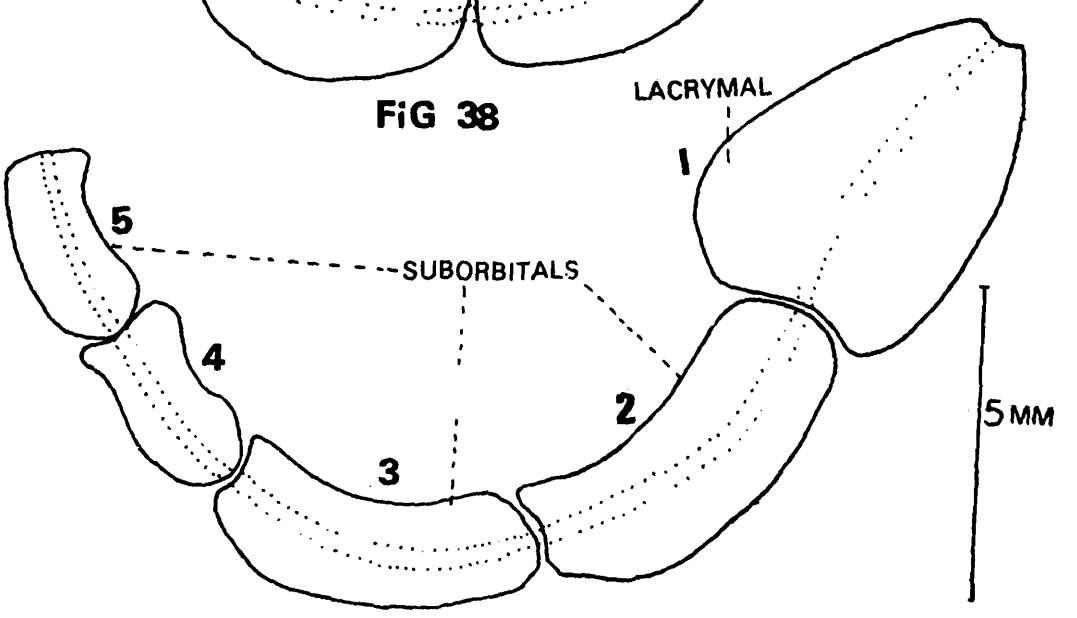


FIG 39

Figs. 37-48. Lateral aspects of suborbital series of *Schizothorax richardsonii*, *Diptychus maculatus*, *Schizopygopsis stoliczkae*, *Ptycobarbus conirostris*, *Schizothoraichthys micropogon*, *S. esocinus*, *S. labiatus*, *Labeo dero*, *Schismatorhynchus nukta*, *Garra lamta*, *Rasbora daniconius*, and *Aspidoparia morar* respectively.

the autopterotic. The articular facets have been described along with the description of the hyomandibular.

Prootic (Figs. 13-24) : Each prootic is a large irregular bone, forming the anteromesial portion of the auditory capsule. The ventromesial portions of the two prootics do not meet in the middle line but articulate mesially with the parasphenoid. It articulates anteriorly with the pterosphenoid, laterally with the autosphenotic and autopterotic and posteriorly with the anterior edge of exoccipital and basioccipital. Its posterior border enters into the subtemporal fossa and is turned upwards.

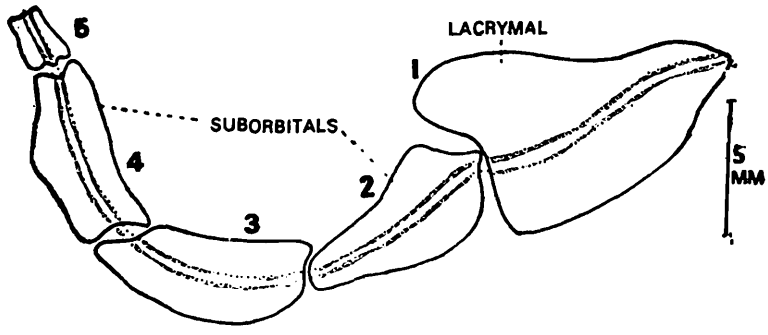


FIG 40

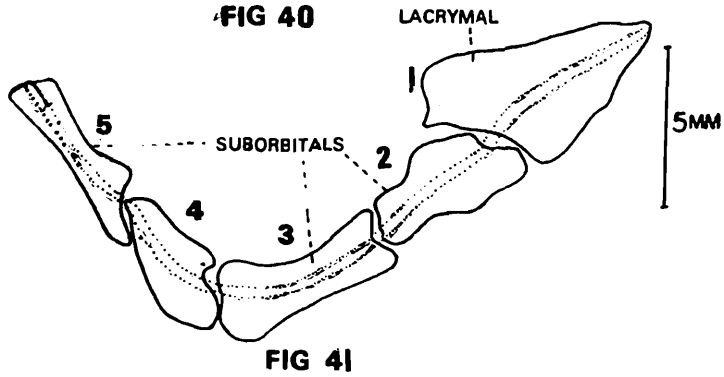


FIG 41

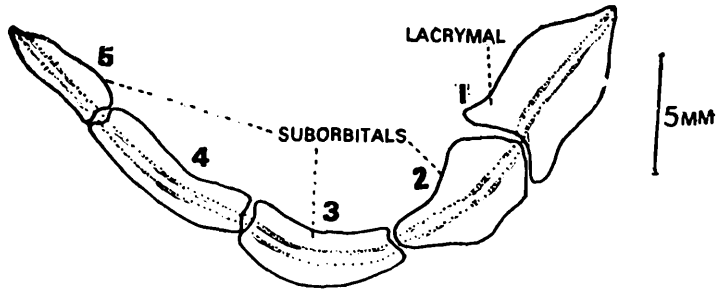


FIG 42

In *Schizothorax richardsonii*, *Schizothoraichthys esocinus* and *Schizothoraichthys labiatus*, the prootic takes a small part in the formation of facet for hyomandibular, whereas it shares about half part in the facet formation in rest of the schizothoracine genera. In the cyprinine genera reported here, the lateral part of the prootic forms the inner bounary of the

facet for hyomandibular while it does not take any part in the formation of this facet in the rasborine genera.

Epiotic (Figs. 1-12 and 25-36) : The posterior part of the roof of the auditory capsule of each side is formed by epiotic which is a bowl-

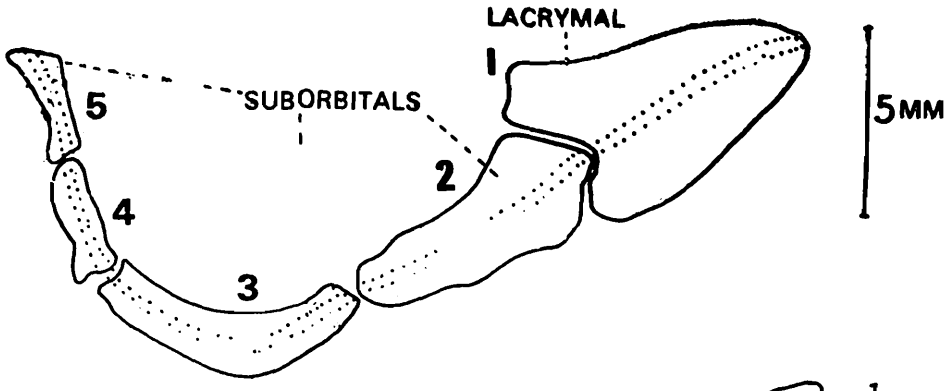


FIG 43

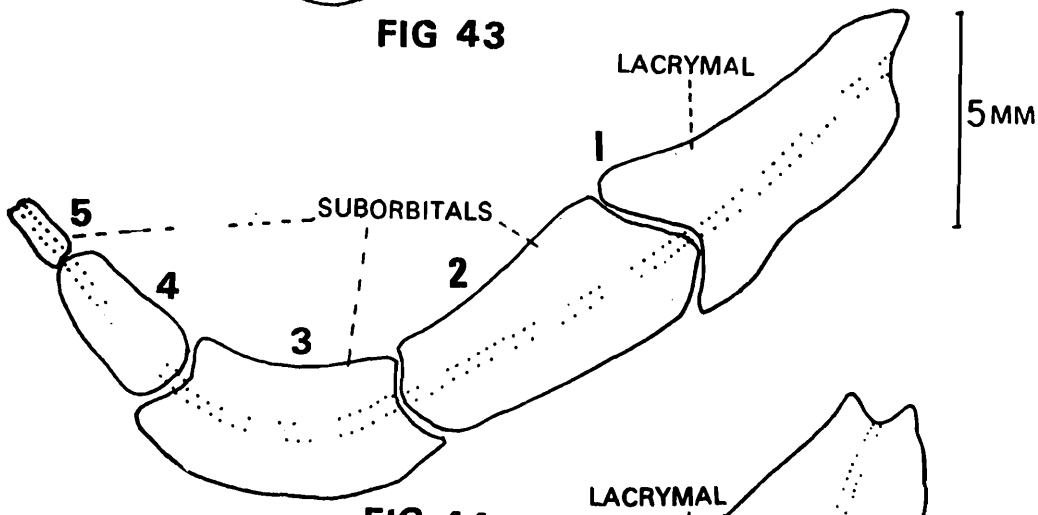


FIG 44

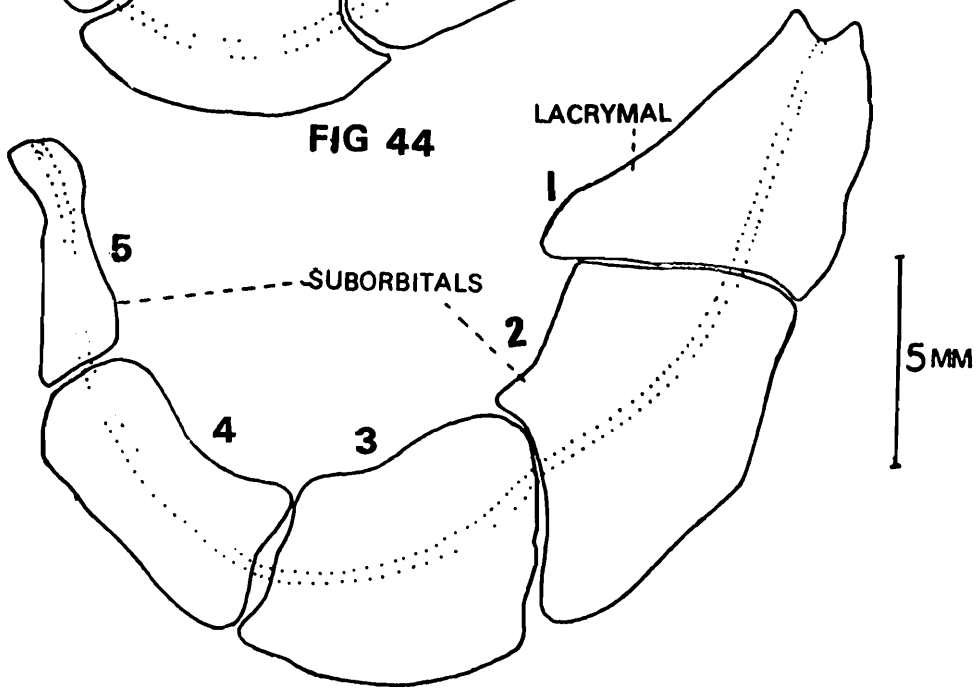


FIG 45

shaped bone. Ventrally, the deep hollow of the bowl accommodates the posterior semicircular canal and is completely surrounded by parie-

tal anteriorly and exoccipital posteriorly. Dorsally, it bears a bony crest which is extended to varying degree. It is very well developed and expanded posteriad into a spine-like process in *Schizothorax richardsonii*

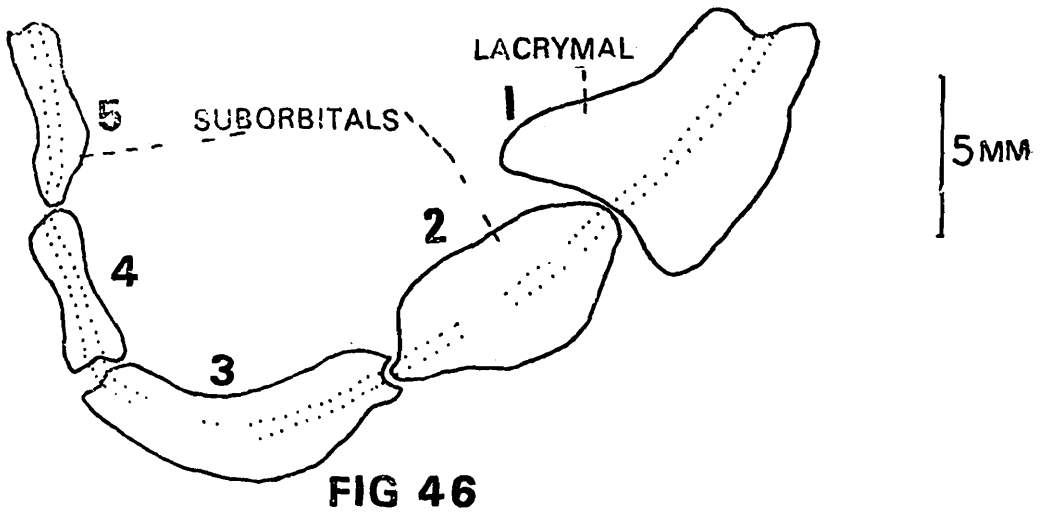


FIG 46

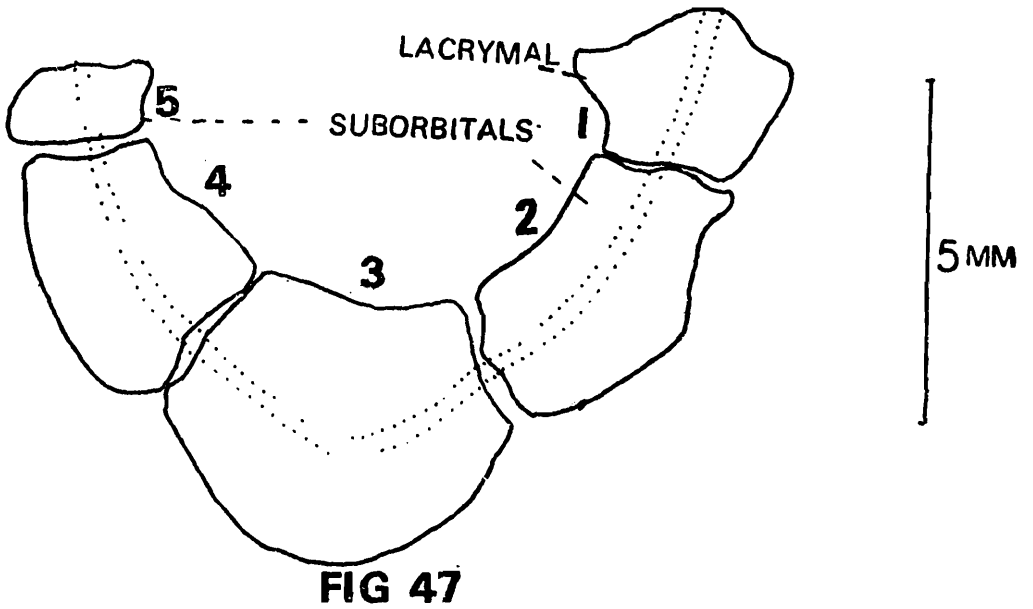


FIG 47

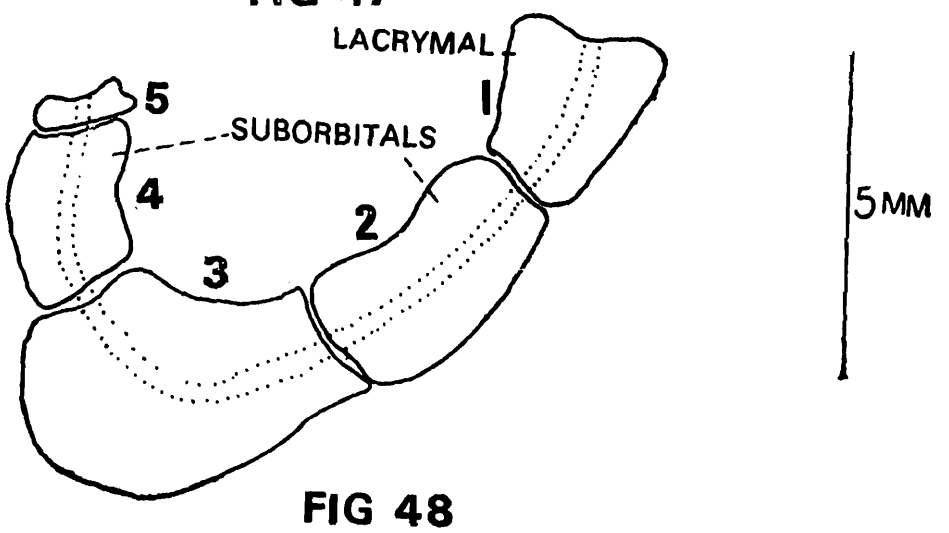
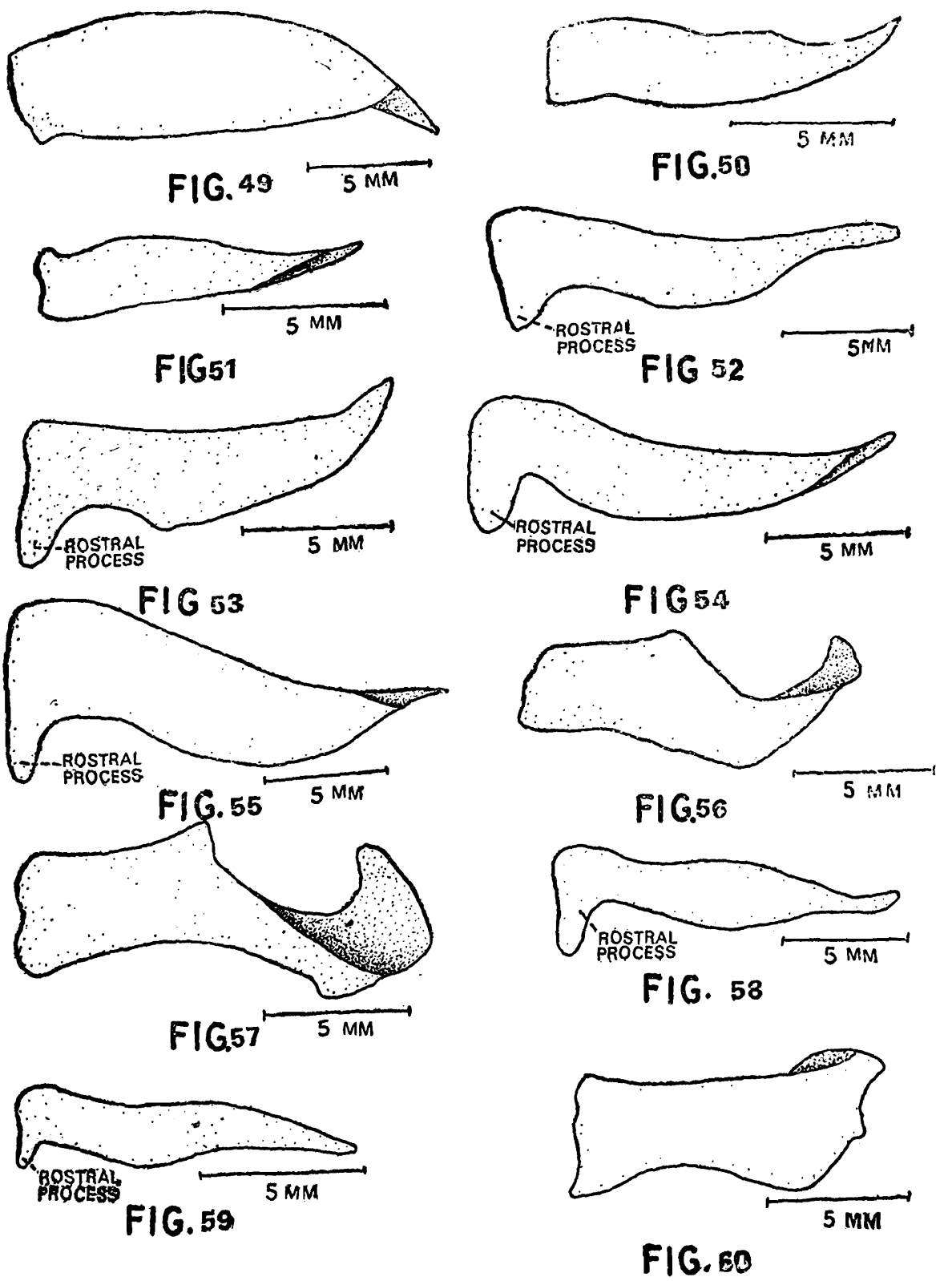


FIG 48

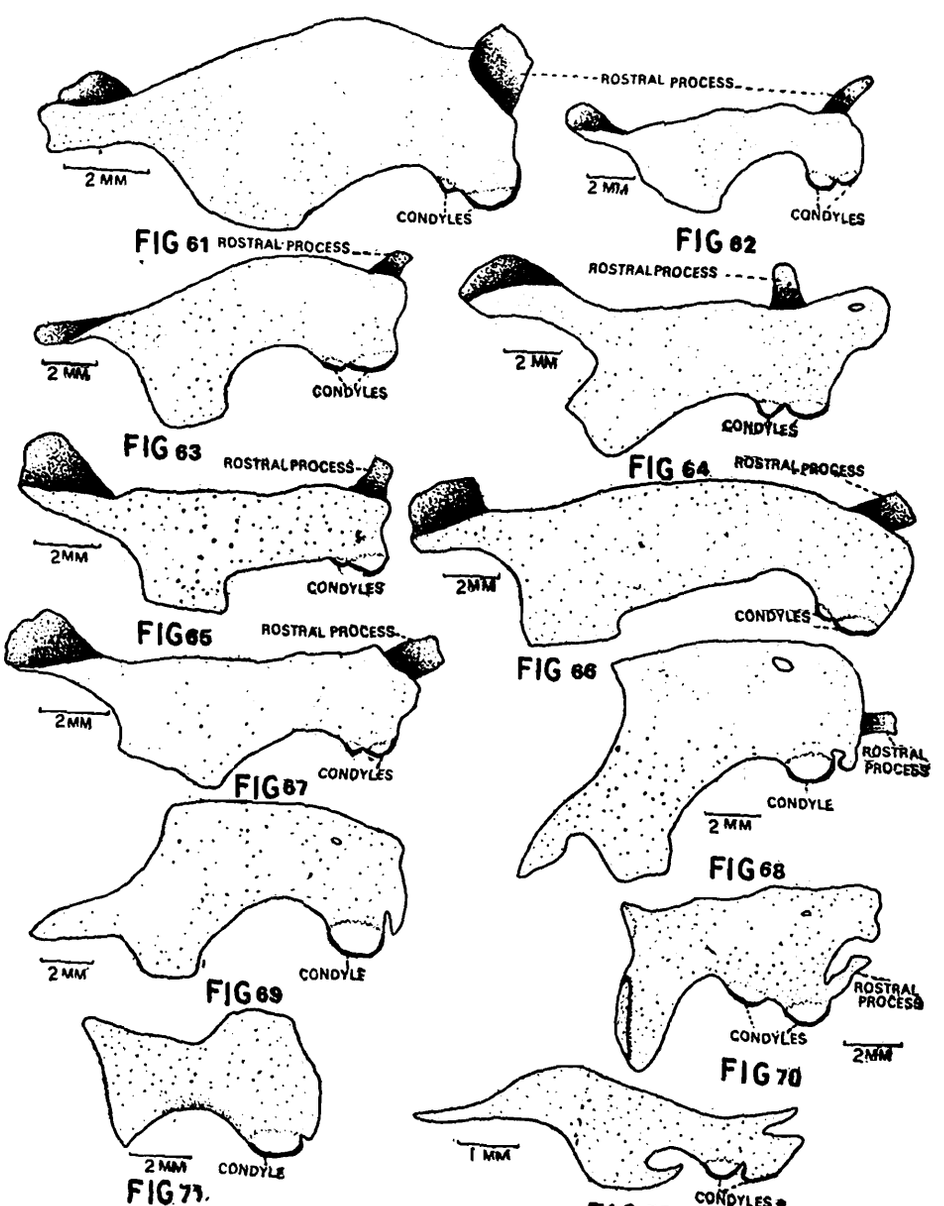
and *Schizothoraichthys labiatus* while in other members of Schizothoracinae and Rasborinae, epiotic crest is low and rounded. Condition is almost similar in *Garra lamta* with the only difference that it has shifted

to the extreme lateral side of the epiotic. In *Labeo dero* and *Schismatorhynchus nukta*, the crest is low but disposed horizontally through whole length of the bulging part of the epiotic.



Figs. 49-60. Dorsal aspects of premaxillaries of *Schizothorax richardsonii*, *Diptychus maculatus*, *Schizopygopsis stoliczkae*, *Ptycobarbus conirostris*, *Schizothoraichthys micropogon*, *S. esocinus* and *S. labiatus*, *Labeo dero*, *Schismatorhynchus nukta*, *Rasbora daniconius*, *Aspidoparia morar* and *Garra lamta* respectively.

Opisthotic (Figs. 13, 16-19) : It is a small, oval bone which overlies the apposing edges of autopterotic and exoccipital on the posteroventral aspect of the rounded margin of the subtemporal fossa. It is an easily detachable bone which neither contributes to the wall of auditory capsule nor retains any connection with the posttemporal. It is present in *Schizothorax richardsonii, Schizothoraichthys spp.* and *Ptycobarbus conirosrris* but absent in all the other genera under report.



Figs. 61-72. Dorsal aspects of maxillaries of *Schizothorax richardsonii, Diptychus maculatus, Schizopygopsis stoliczkae, Ptycobarbus conirostris, Schizothoraichthys micropogon, S. esocinus, S. labiatus, Garra lamta, Aspidoparia morar* and *Rasbora daniconius* respectively.

Parietal (Figs. 1-12) : Each parietal is a large, smooth bone, lying on the dorsal aspect of the auditory capsule. The general shape of the parietal is similar in all the species studied. However, it is observed

that they are slightly longer in *Diptychus maculatus*, *Schizopygopsis stoliczkae*, *Rasbora daniconius* and *Aspidoparia morar* when compared with the frontals.

Posttemporal (Figs. 1-12) : It is a thin, splint-like bone which is attached by ligaments to the posterior part of autopterotic. The posterior end of the bone is bifid which articulates with the upper end of supracleithrum and lies posterior to the supratemporal.

Supratemporal (Figs. 1-12) : It is a small bone attached to the skull and lies anterior to the posttemporal, with a slight variation in all the genera under report.

2. *Branchiocranium*

(i) *Oromandibular Region* :

This region is formed by the upper and lower jaws.

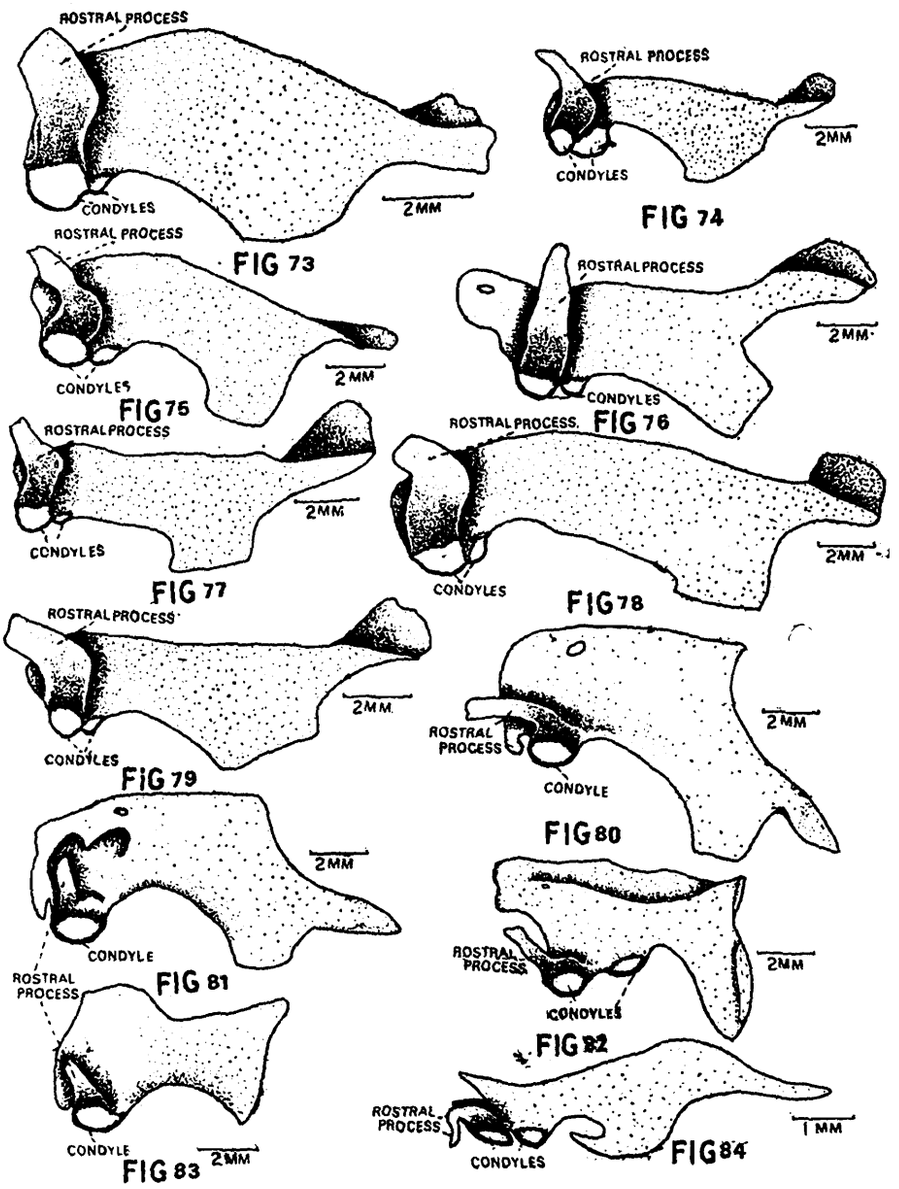
Upper jaws : It consists of the paired premaxillaries, maxillaries, the ectopterygoids, the entopterygoids, the metapterygoids, the quadrates and the autopalatines.

Premaxillary (Figs. 49-60) : Each premaxillary is a curved bone which meets its fellow of its oppsite side in the medial line through a sheath of thin fibrous tissue and forms a symphysis. It has a flat and strong body which may or may not bear a backwardly directed prominent process-the rostral process-at its mesial end. This process is absent in *Diptychus maculatus*, *Schizopygopsis stoliczkae* and *Garra lamta* and is very much reduced in *Schizothorax richardsonii*, *Labeo dero* and *Schismatorhynchus nukta* while in *Schizothoraichthys* spp., *Rasbora daniconius* and *Aspidoparia morar*, this process is well developed and prominent. The posterior end of the premaxillary symphysis is attached to the dorsal end of the kinethmoid (rostral bone) through a sigmoid ligament. The latter has a unique correlation with the length of the rostral process. The length of the sigmoid ligament is inversely proportion to the length of the rostral process of premaxillary.

Each premaxillary is thicker and stouter in *Schizothorax richardsonii*, *Diptychus maculatus*, *Schizopygopsis stoliczkae*, *Labeo dero* and *Schismatorhynchus*, *nukta* as compared to other species under report, However, the premaxillaries of *Labeo dero* and *Schismatorhynchus nukta* differ from those of schizothoracine genera in those their width is uniform from the proximal to the distal ends with a slight anterior projection somewhere in the middle of their length. In *Garra lamta*, each premaxillary is bent sharply (at 90°) near its distal end where it forms a slightly articular facet for its articulation with the ventral face of the distal end

of maxillaries. Such an articular facet is absent in all other species studied.

Maxillary (Figs. 61-84) : Each maxillary is a stout bone which lies parallel and posterior to the premaxillary on the dorsal aspect. Normally, in 'closed mouth condition', the maxillaries overlie the premaxillaries in all the species studied except in *Garra lamta* where



Figs. 73-84. Ventral aspects of maxillaries of *Schizothorax richardsonii, Diptychus maculatus, Schizopygopsis stoliczkae, Ptycobarbus conirostris, Schizothoraichthys micropogon, S. esocinus, S. labiatus, Labeo dero, Schismatorhynchus nukta, Garra lamta, Aspidoparia morar* and *Rasbora daniconius* respectively.

they come to lie anteriad and take part in the formation of snout. Each maxillary has a thick body, a broad and strong mesial process and a thin and curved lateral process ; the latter is thinner in *Labeo dero* and *Schismatorhynchus nukta* as compared to other species under

report. From the ventral aspect of the mesial end of maxillary, just in front of the mesial articular condyles, arises a broad rostral process which runs medioanteriorly and is connected to its fellow of the other side only through a band of ligaments in which the ventral tip of the kinethmoid is embedded. In *Ptycobarbus conirostris*, this process runs anteriorly and tips of the rostral processes of the two sides remain quite apart and the ligament connecting them is large.

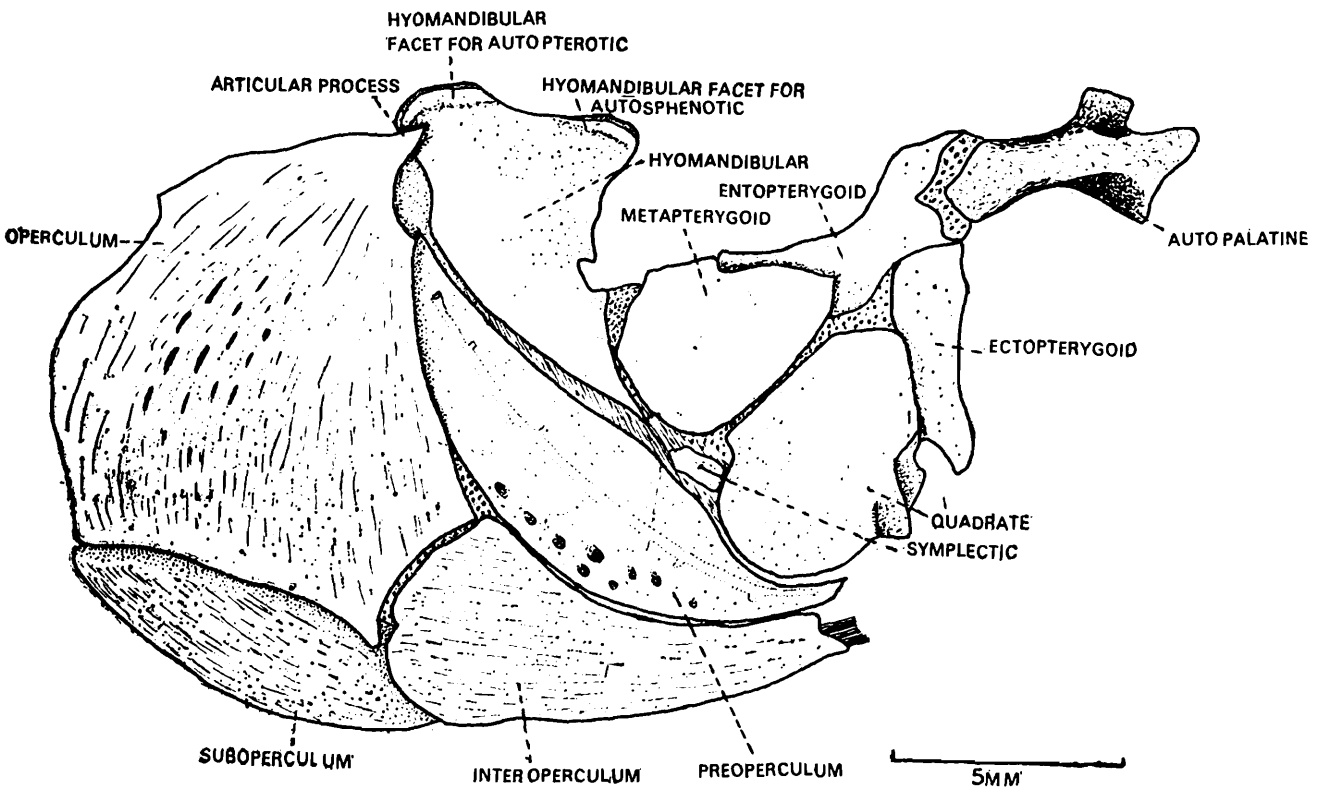


FIG 85

Figs. 85-96. Outer aspects of the upper jaw bones and the opercular series of the right side of *Schizothorax richardsonii*, *Diptychus maculatus*, *Schizopygopsis stoliczkae*, *Ptycobarbus conirostris*, *Schizothoraichthys micropogon*, *S. esocinus S. labiatus*, *Labeo dero*, *Schismatorhynchus nukta*, *Garra lamta*, *Aspidoparia morar* and *Rasbora daniconius* respectively.

Just behind the origin of the rostral process, the mesial ends of maxillaries bear one or two articular condyle/condyles. There is a single articular condyle in *Labeo dero*, *Schismatorhynchus nukta* and *Aspidoparia morar* while in *Schizothorax richardsonii*, the outer articular condyle is negligibly small and inner one is moderately developed. In *Diptychus maculatus*, *Garra lamta* and *Rasbora daniconius*, the two condyles are almost of equal dimensions whereas in *Schizopygopsis stoliczkae*, *Ptycobarbus conirostris* and *Schizothoraichthys spp.*, the inner condyle is much bigger than the outer one. These articular condyles of each maxillary along with the articular concavities of the anterior

end of the autopalatine together articulate with the rounded tip of the prevomer.

In *Labeo dero*, *Schismatorhynchus nukta* and *Aspidoparia morar*, there is a small process arising just anterior to the articular condyles. This process is crochet-shaped and directed backwards in the former two species while it is hook-like in the latter.

At the base of the lateral process of each maxillary there is a posterior projection which is very prominent in *Ptycobarbus conirostris* as compared to other species. The projection is overlapped by the anterior part of lacrymal (suborbital I).

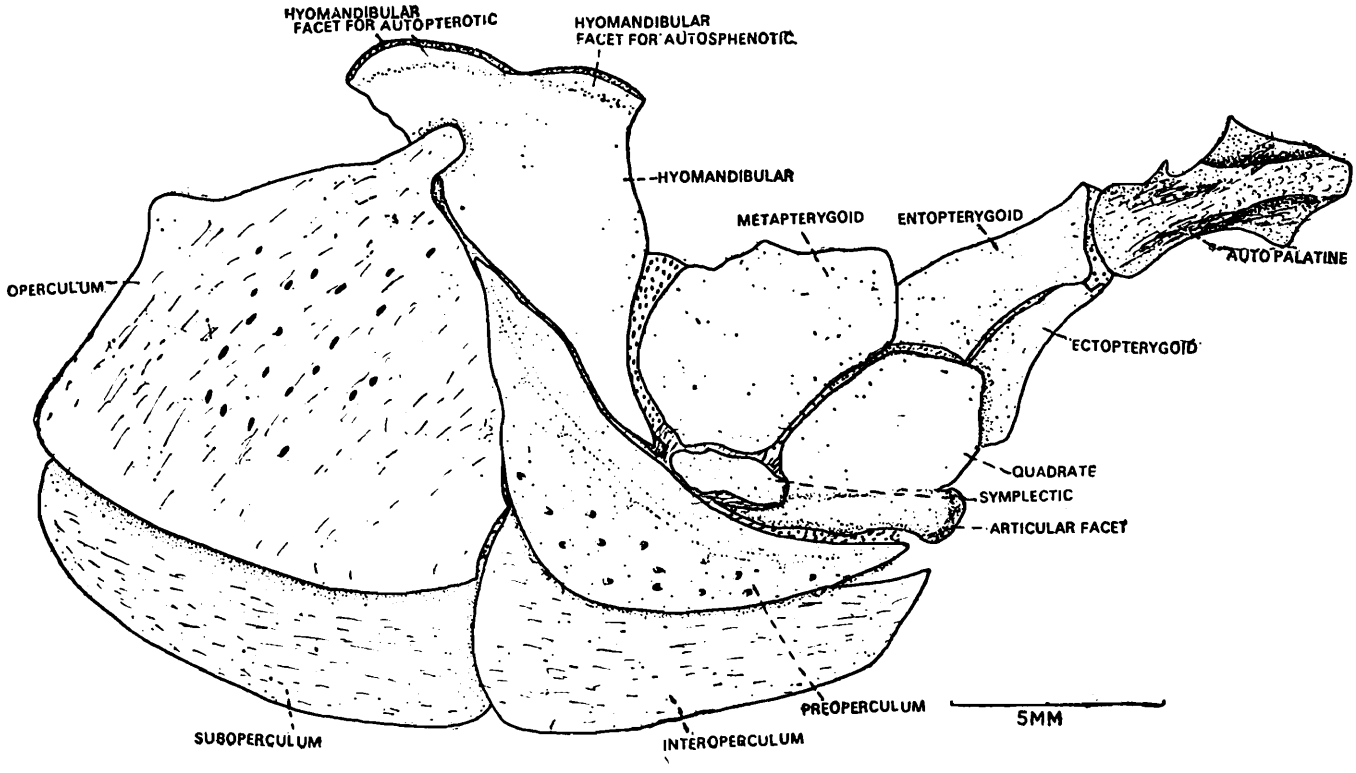


FIG 86

There is a prominent foramen piercing through the body of maxillary in *Ptycobarbus conirostris*, *Labeo dero*, *Garra lamta* and *Schismatorhynchus nukta*. This foramen is absent in the rest of the species.

Ectopterygoid (Fig. 85-108) : Each ectopterygoid is a long, plate-like bone which articulates anteriorly with the posterior border of the autopalatine and posteriorly with the quadrate. The manner of attachment of this bone is similar in all the species worked out.

Entopterygoid (Figs. 85-108) ; It is a plate-like bone whose posterior end is broad and anterior is relatively narrow. It lies above the ectopterygoid and the two together form the floor of the orbit. Its inner end extends up to the stem of parasphenoid. It articulates anteriorly

with the posterior end of autopalatine, and posteriorly, with metapterygoids. There is little variation in this bone in all the genera under report.

Metapterygoid (Figs. 85-108) : Each metapterygoid is a large, broad bone placed almost vertically parallel to the long axis of the skull, just behind the entopterygoid. Its posterior angle is applied to the anterior part of hyomandibular. Its posterior edge is attached to the medial dorsal side of symplectic. Not much variation is seen in this bone in all the genera studied.

Quadrate (Figs. 85-108) : It is a broad and flat bone, posteriorly produced into a long, thick, handle- like process which is separated from the metapterygoid by the symplectic. At its anteroventral angle,

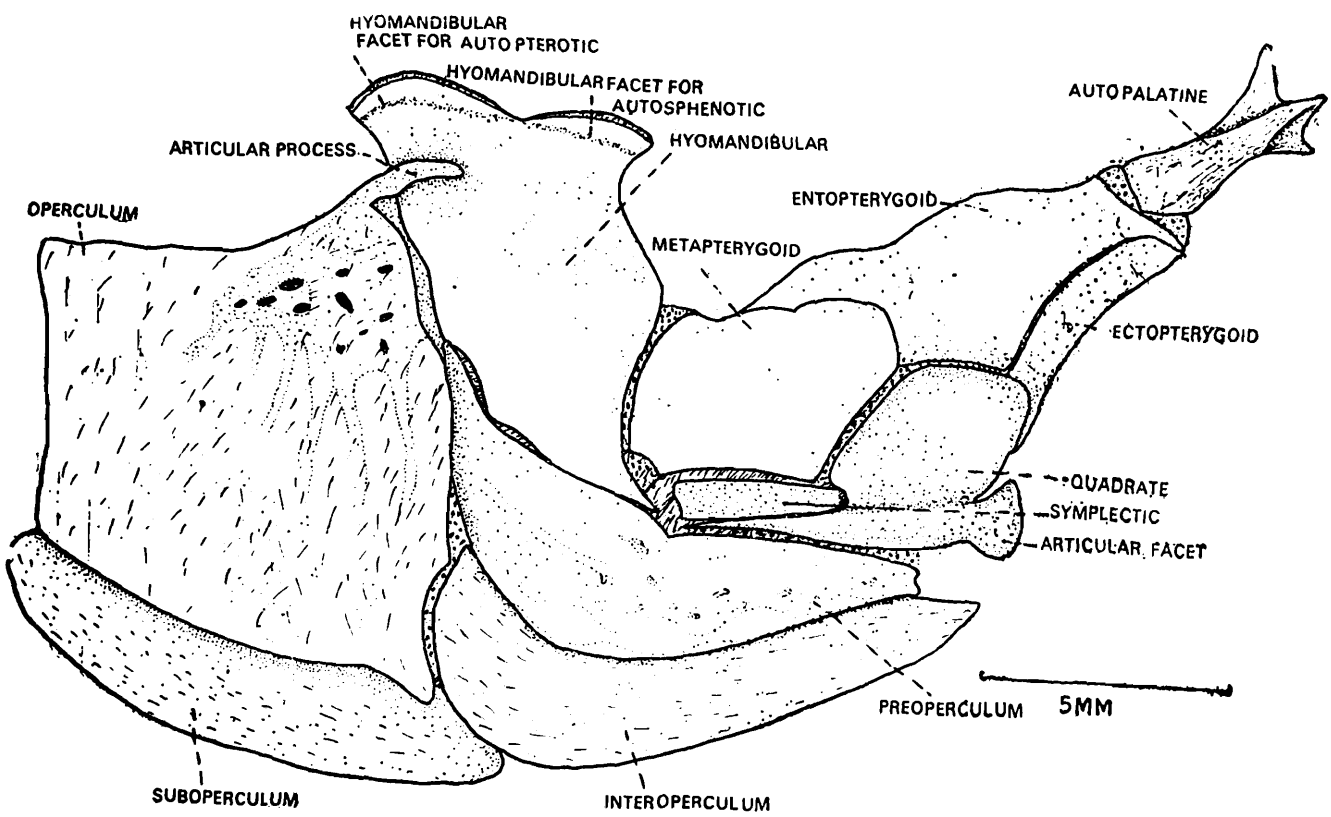


FIG 87

it has an articular facet for a movable attachment of the lower jaw. The degree of development of the facet varies according to the development of respective lower jaw. The facet is thick and stout in *Schizothorax richardsonii* and *Garra lamta* whereas it is less so in all the other genera.

Autopalatine (Figs. 85-108) : It is a long, cylindrical, toothless bone, broader at two extremities and narrow in the middle. It lies above

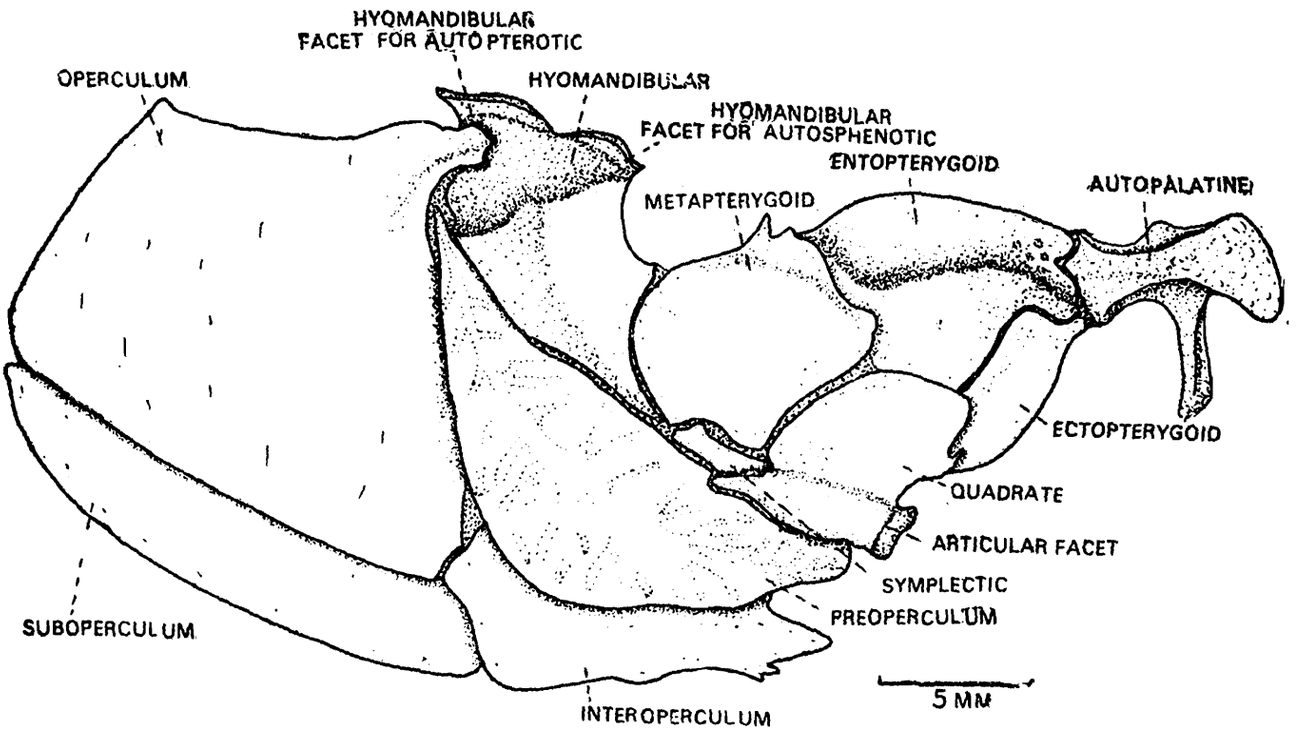

HYOMANDIBULAR FACET FOR AUTOPTEROTIC
OPERCULUM
HYOMANDIBULAR
HYOMANDIBULAR FACET FOR AUTOSPHENOTIC
ENTOPTERYGOID
AUTOPALATINE
METAPTERYGOID
ECTOPTERYGOID
QUADRATE
ARTICULAR FACET
SYMPLECTIC
PREOPERCULUM
SUBOPERCULUM
INTEROPERCULUM
5 MM

FIG 88

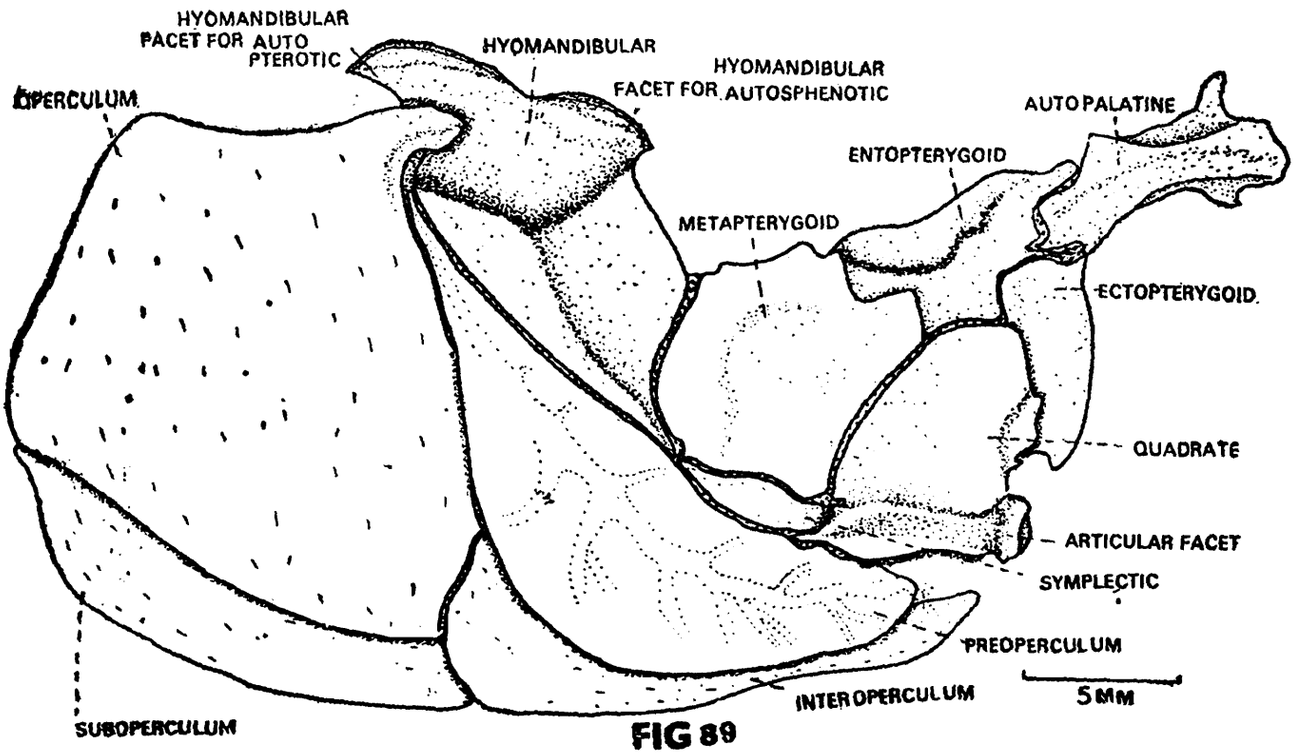

HYOMANDIBULAR FACET FOR AUTO PTEROTIC
HYOMANDIBULAR
HYOMANDIBULAR FACET FOR AUTOSPHENOTIC
OPERCULUM
AUTOPALATINE
ENTOPTERYGOID
METAPTERYGOID
ECTOPTERYGOID
QUADRATE
ARTICULAR FACET
SYMPLECTIC
PREOPERCULUM
INTEROPERCULUM
5MM
SUBOPERCULUM

FIG 89

the orbit, just lateral to the prevomer and lacrymal. Posteriorly, it is immovably articulated with the anterior ends of ecto- and entopterygoid. Its antero inner end bears an articular concavity into which the preethmoid and the anterior end of prevomer fits in. The articular concavity is rounded in schizothoracine, rasboranine genera and *Garra lamta* and elongated in *Labeo dero* and *Schismatorhynchus nukta*.

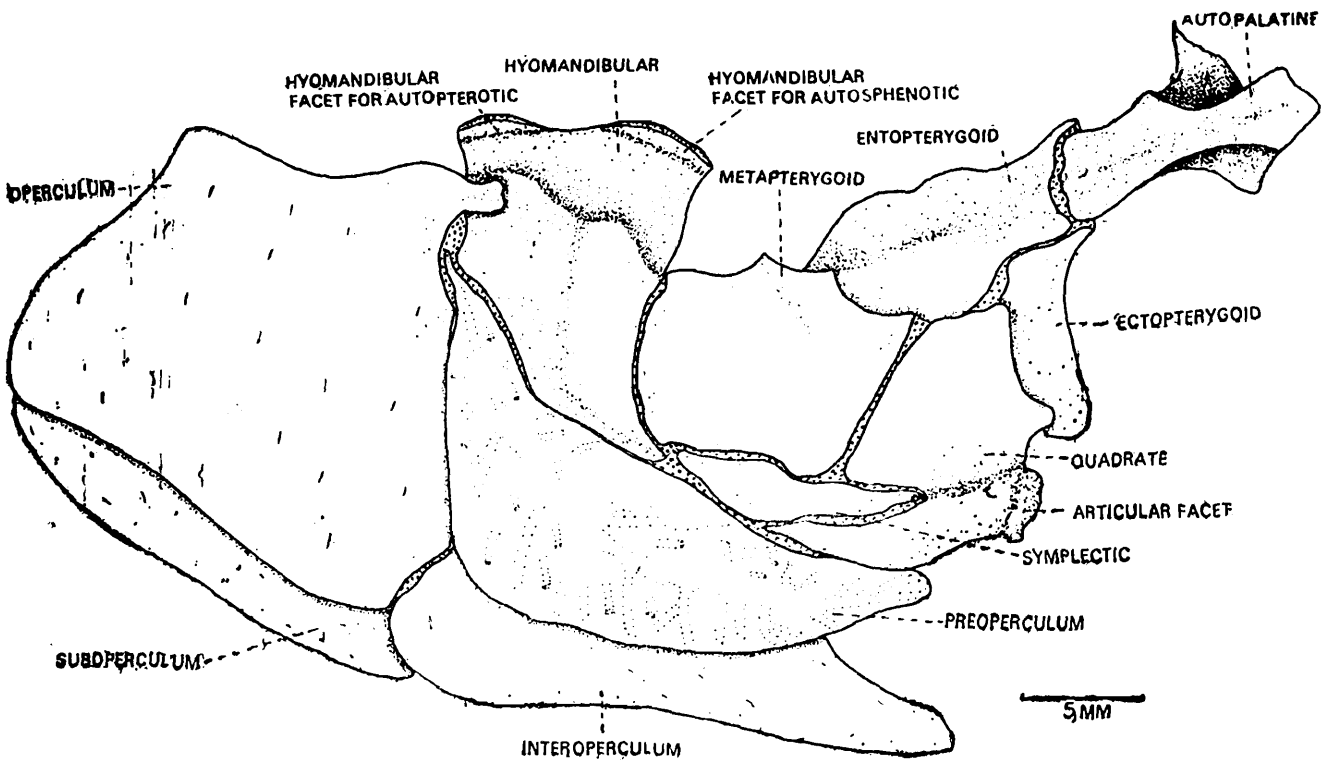


FIG 90

On the antero outer aspect of each autopalatine, one or two articular facets develop into which the maxillary condyles articulate. Thus, the antero outer aspect is accordingly divided into two processes, the extent of which differs in different species. In *Schizothorax richardsonii*, one articular facet is very weakly developed than the other whereas in *Diptychus maculatus*, *Garra lamta* and *Rosbora daniconius*, the two articular facets of the autopalatine are equally developed to house two equal condyles of the maxillary. In *Schiszopygopsis stoliczkae*, *Ptycobarbus conirotrsis* and *Schizothoraichthys spp.*, one fact is slightly less developed than the other. In *Labeo dero*, *Schismatorhynchus nukta*, *Aspidoparia morar*, one facet is well developed to accommodate a single condyle of maxillary while the crochet- like process of maxillary of *Labeo dero* and *Schismatorhynchus nukta* or a hook- like process of the maxillary of *Aspidoparia morar* is also housed in a small articular facet at the antero outer aspect of each autopalatine.

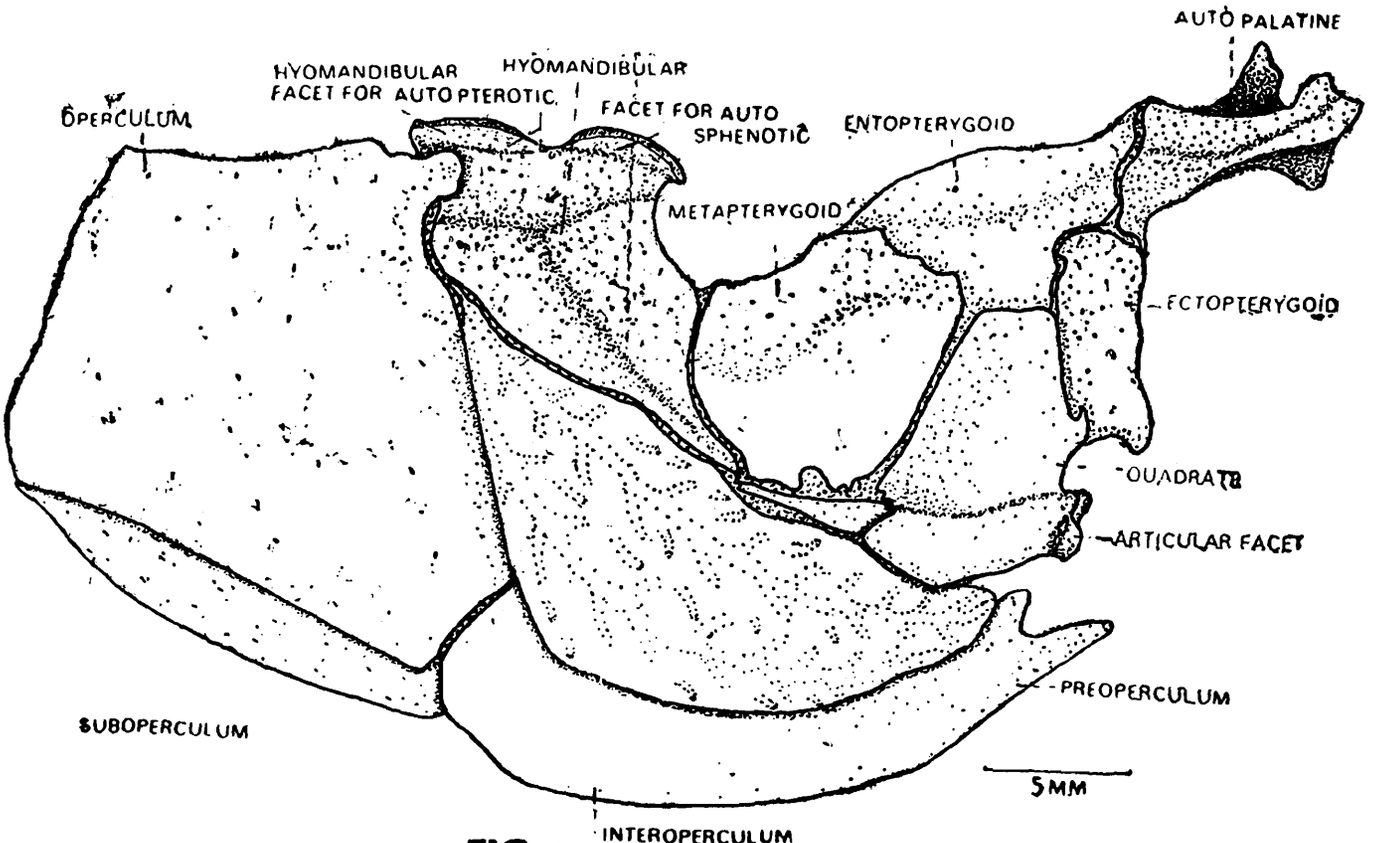

AUTO PALATINE
HYOMANDIBULAR FACET FOR AUTOPTEROTIC
HYOMANDIBULAR FACET FOR AUTO SPHENOTIC
OPERCULUM
ENTOPTERYGOID
METAPTERYGOID
ECTOPTERYGOID
QUADRATE
ARTICULAR FACET
PREOPERCULUM
SUBOPERCULUM
5MM
INTEROPERCULUM

FIG 91

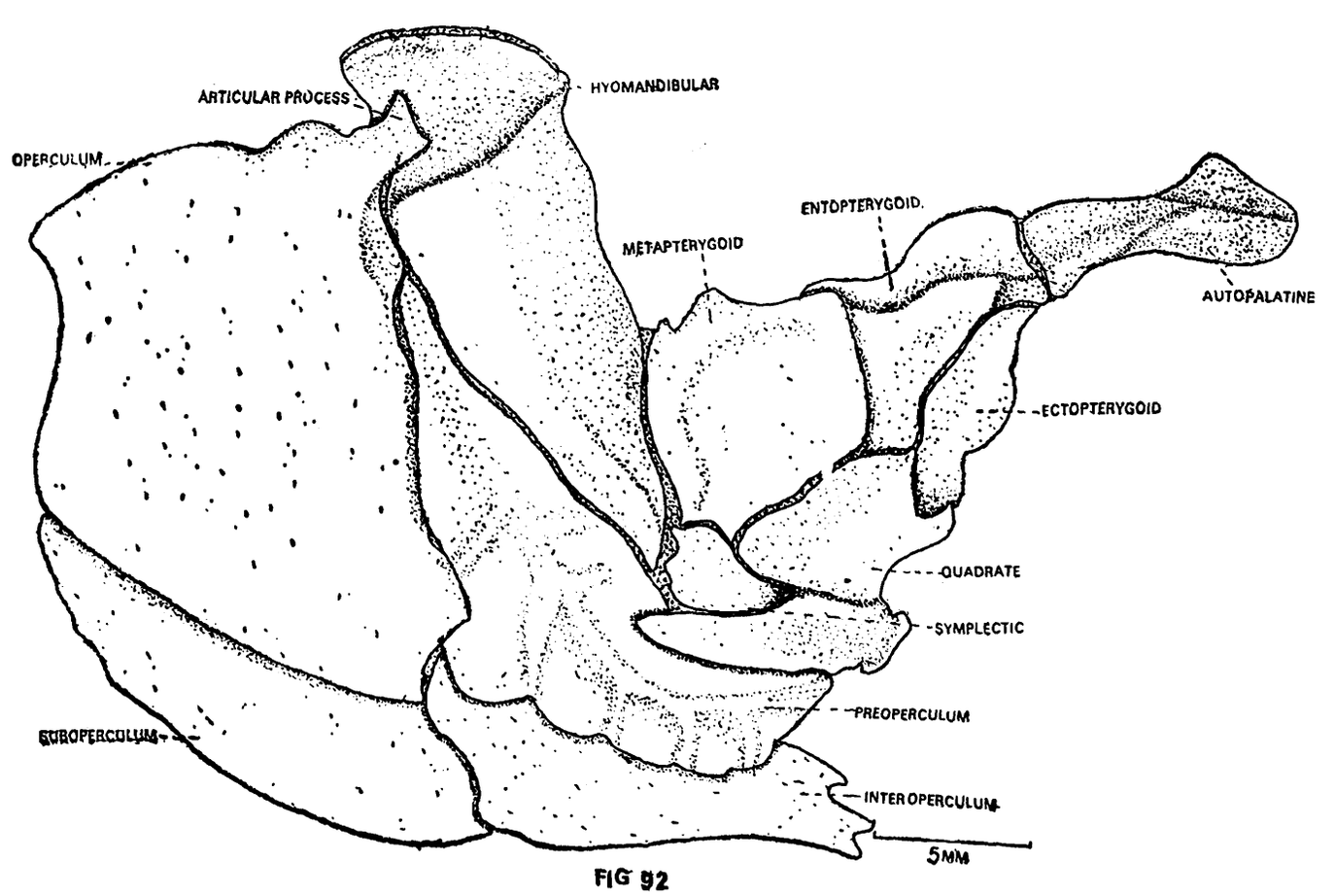

ARTICULAR PROCESS
HYOMANDIBULAR
OPERCULUM
ENTOPTERYGOID
METAPTERYGOID
AUTOPALATINE
ECTOPTERYGOID
QUADRATE
SYMPLECTIC
PREOPERCULUM
SUBOPERCULUM
INTEROPERCULUM
5MM

FIG 92

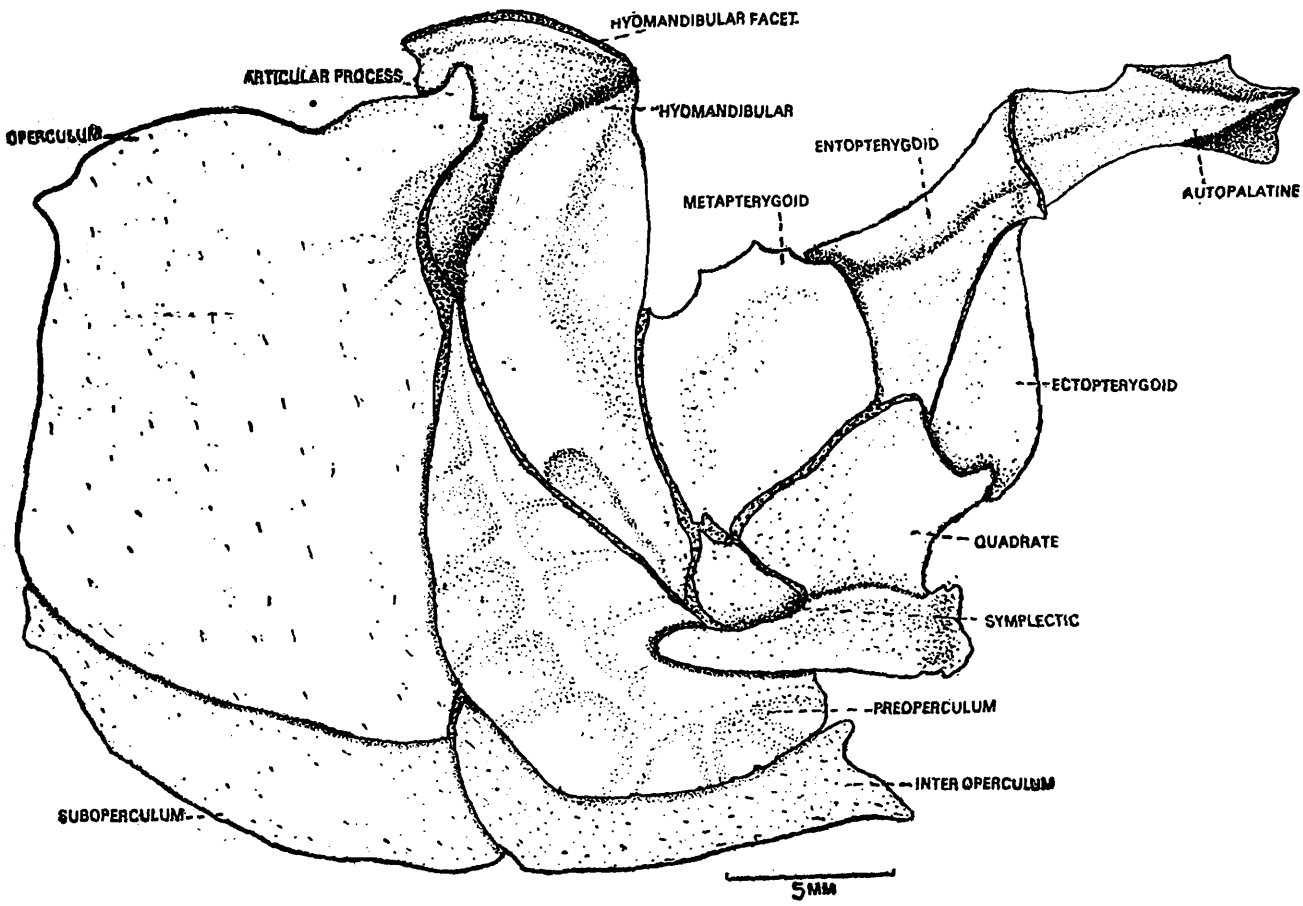

HYOMANDIBULAR FACET
ARTICULAR PROCESS
OPERCULUM
HYOMANDIBULAR
ENTOPTERYGOID
METAPTERYGOID
AUTOPALATINE
ECTOPTERYGOID
QUADRATE
SYMPLECTIC
PREOPERCULUM
INTER OPERCULUM
SUBOPERCULUM
5MM

FIG 93

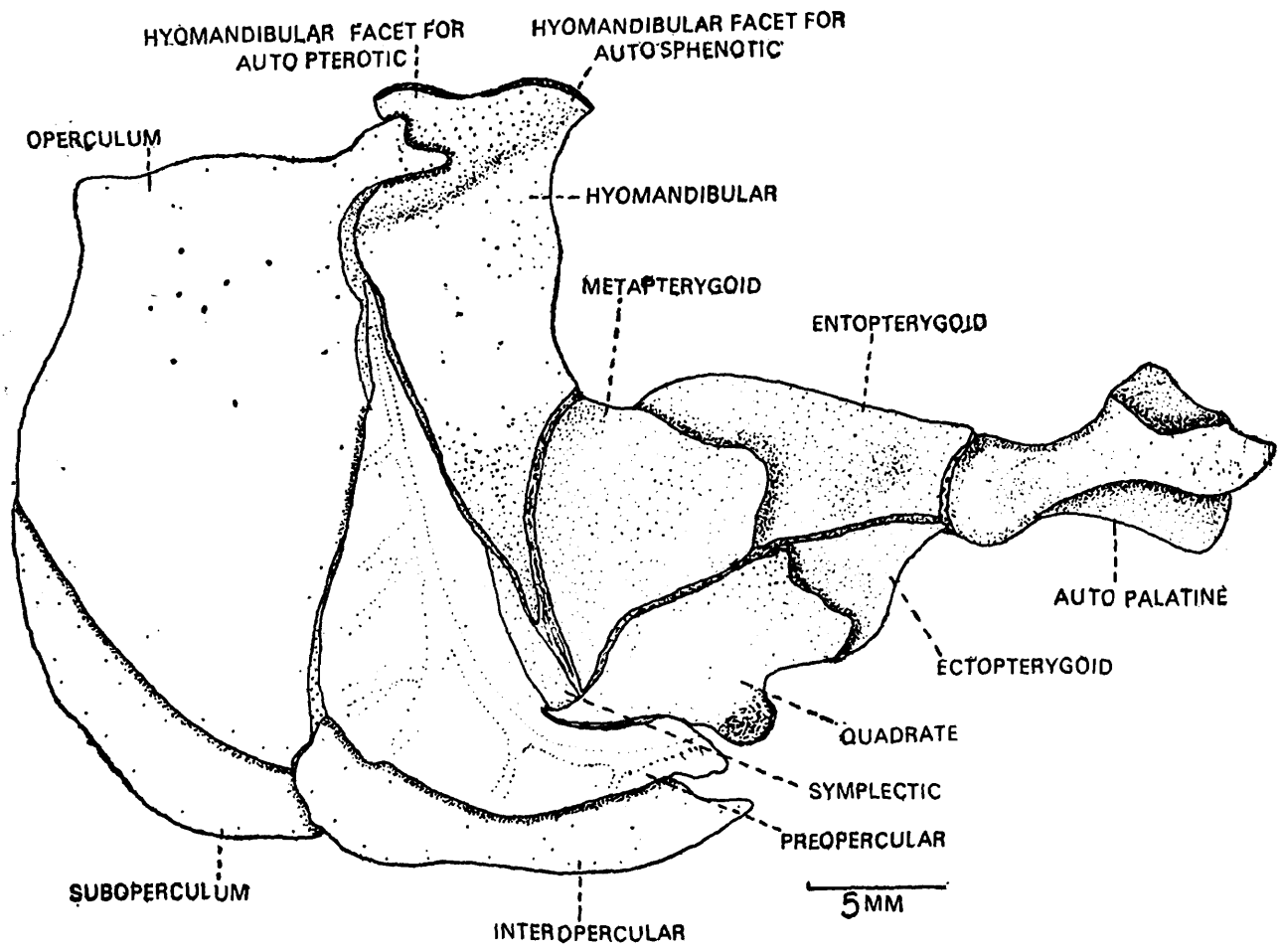

HYOMANDIBULAR FACET FOR AUTO PTEROTIC
HYOMANDIBULAR FACET FOR AUTO SPHENOTIC
OPERCULUM
HYOMANDIBULAR
METAPTERYGOID
ENTOPTERYGOID
AUTO PALATINE
ECTOPTERYGOID
QUADRATE
SYMPLECTIC
PREOPERCULAR
SUBOPERCULUM
INTEROPERCULAR
5MM

FIG 94

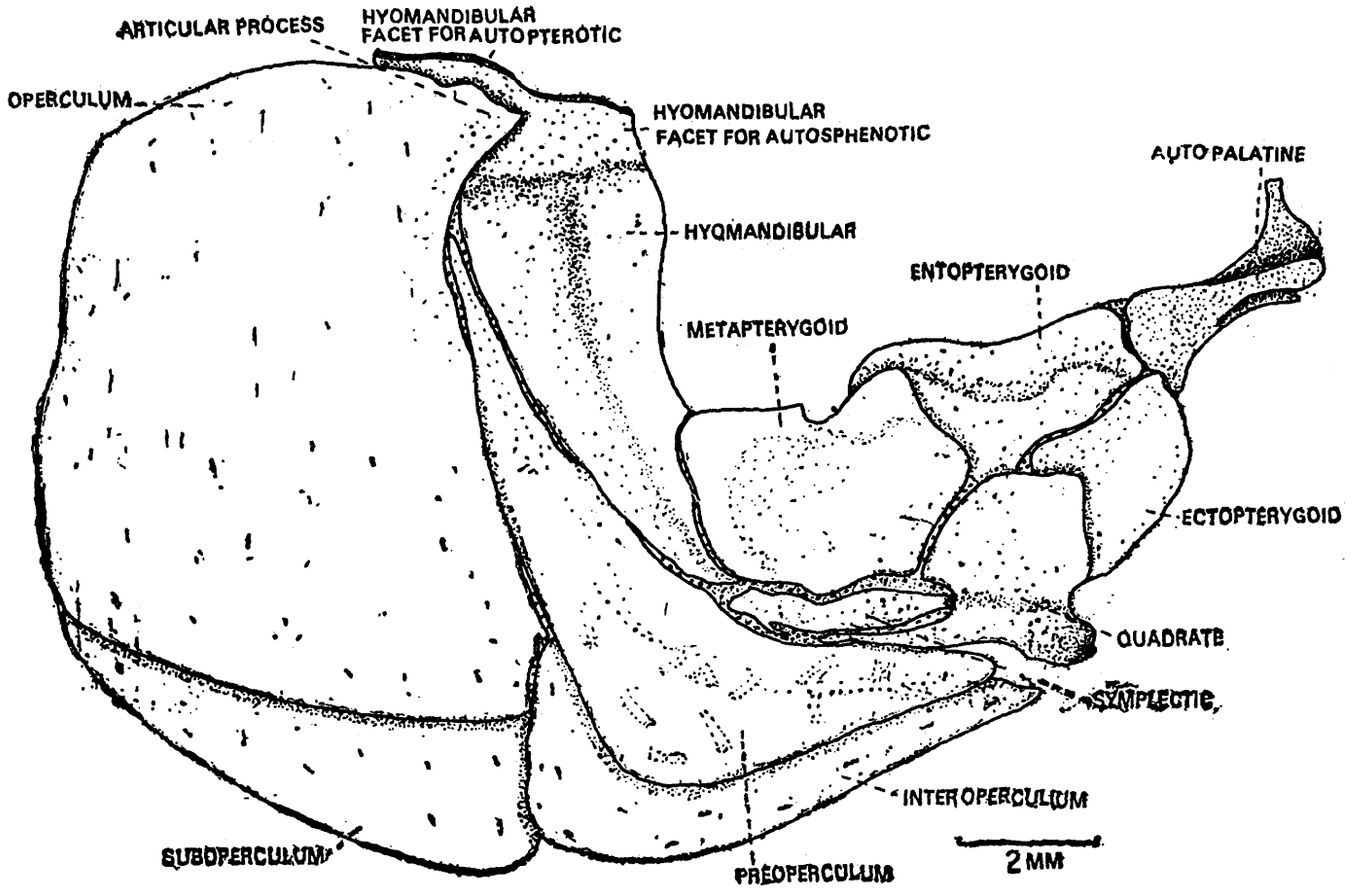

ARTICULAR PROCESS
HYOMANDIBULAR FACET FOR AUTOPTEROTIC
OPERCULUM
HYOMANDIBULAR FACET FOR AUTOSPHENOTIC
HYOMANDIBULAR
AUTOPALATINE
ENTOPTERYGOID
METAPTERYGOID
ECTOPTERYGOID
QUADRATE
SYMPLECTIC
INTEROPERCULUM
SUBOPERCULUM
PREOPERCULUM
2 MM

FIG 95

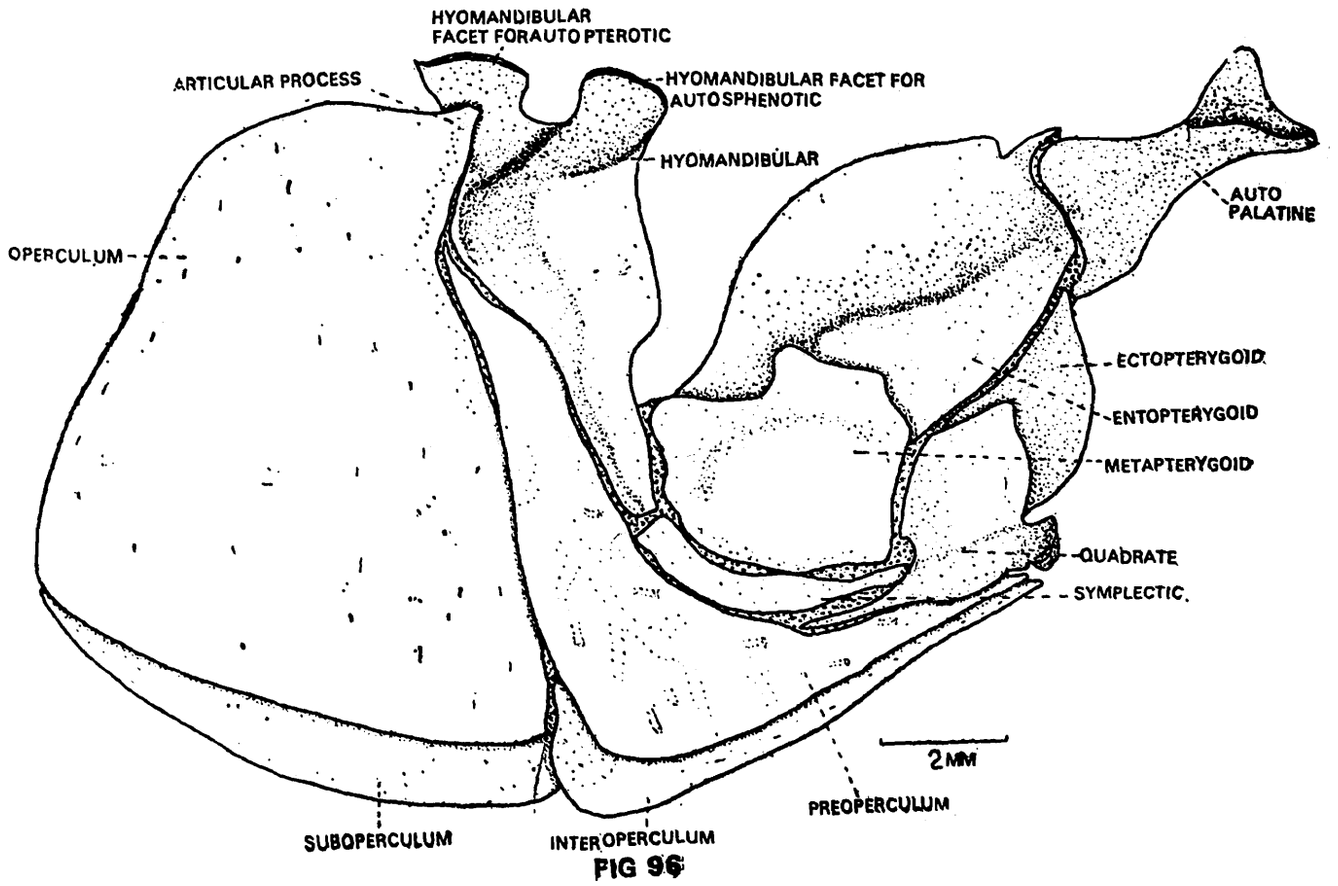

HYOMANDIBULAR FACET FOR AUTOPTEROTIC
ARTICULAR PROCESS
HYOMANDIBULAR FACET FOR AUTOSPHENOTIC
HYOMANDIBULAR
AUTO PALATINE
OPERCULUM
ECTOPTERYGOID
ENTOPTERYGOID
METAPTERYGOID
QUADRATE
SYMPLECTIC
2 MM
PREOPERCULUM
SUBOPERCULUM
INTEROPERCULUM

FIG 96

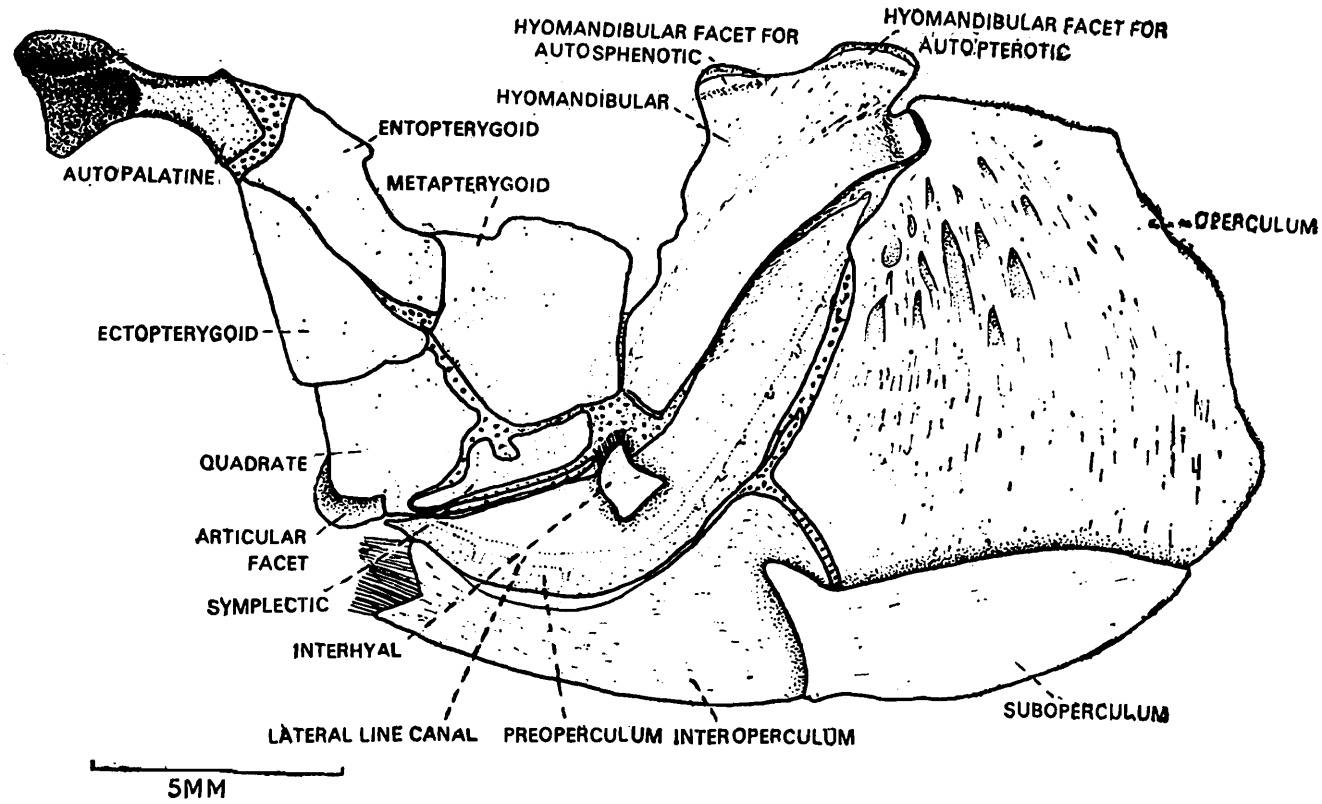


FIG 97

Figs. 97-108. Inner aspects of the upper jaw bones and the opercular series of the right side of *Schizothorax richardsonii, Diptychus maculatus, Schizopygopsis stoliczkae, Ptycobarbus conirostris, Schizothoraichthys micropogon, S. esocinus, S. labiatus Labeo dero, Schismatorhynchus nukta, Garra lamta, Aspidoparia morar* and *Rasbora daniconius* respectively.

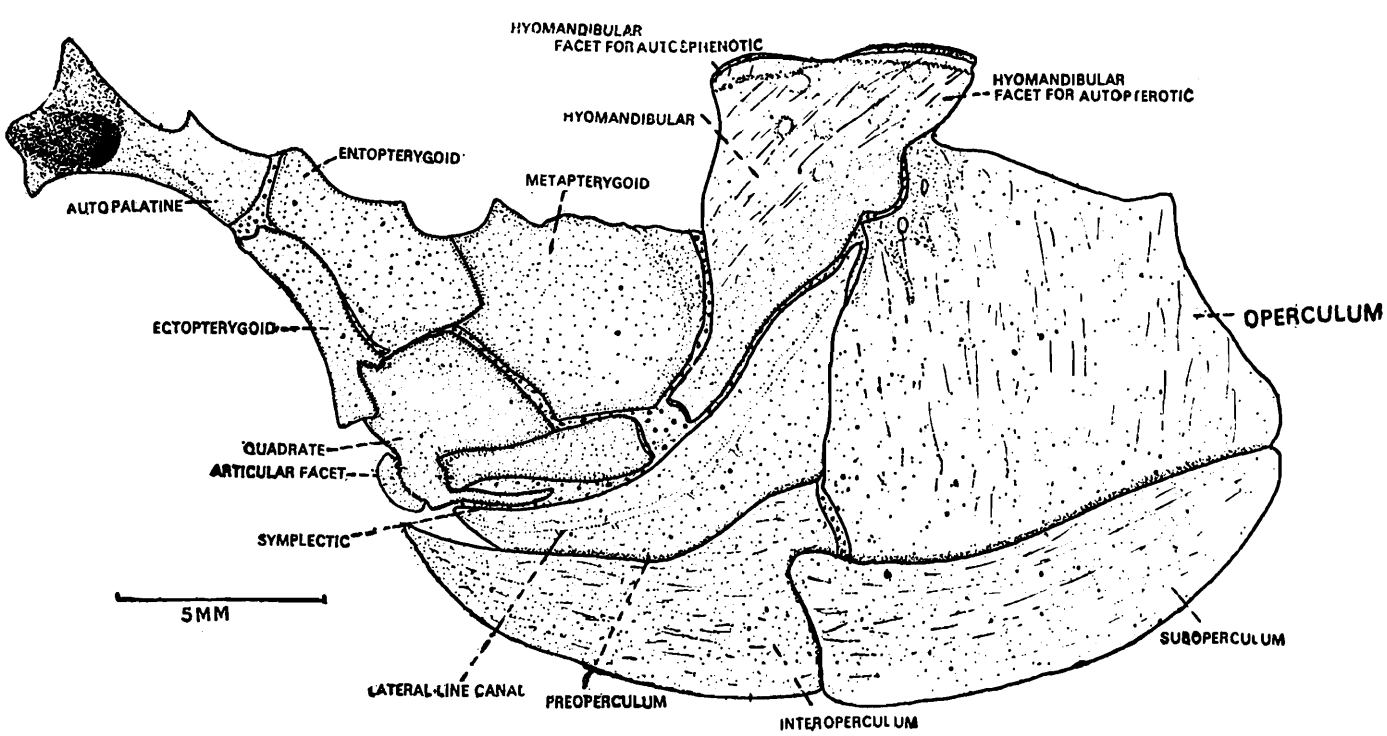


FIG 98

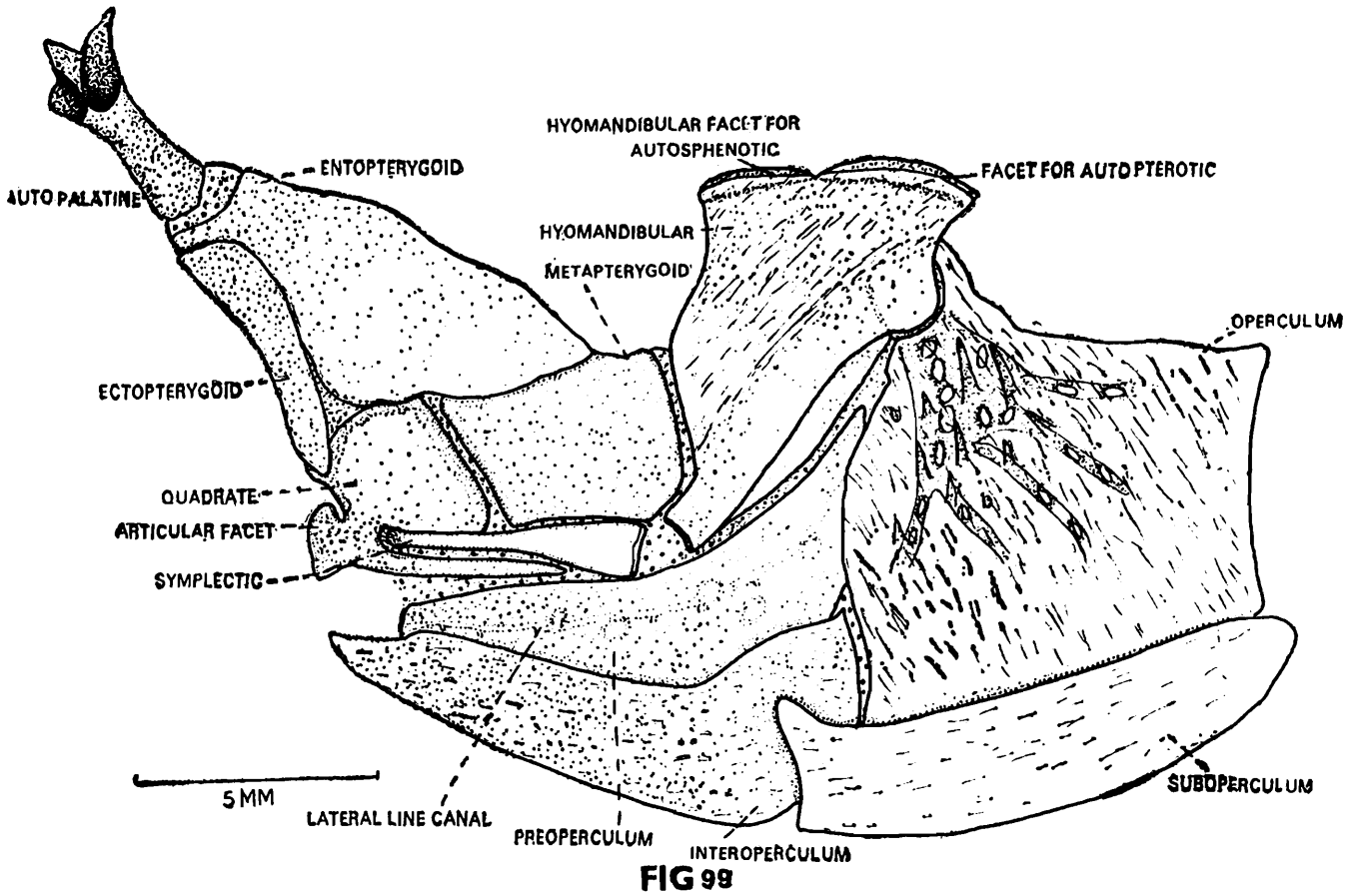


FIG 99

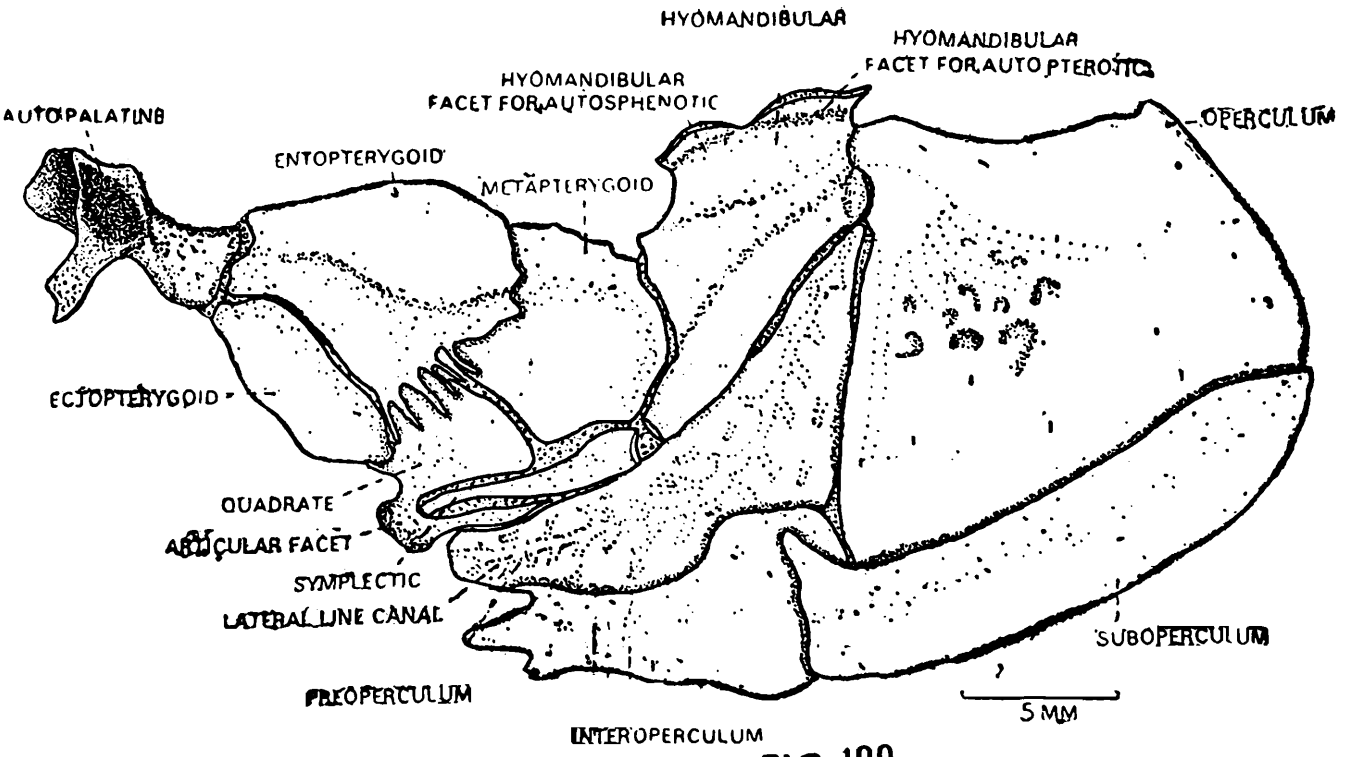


FIG 100

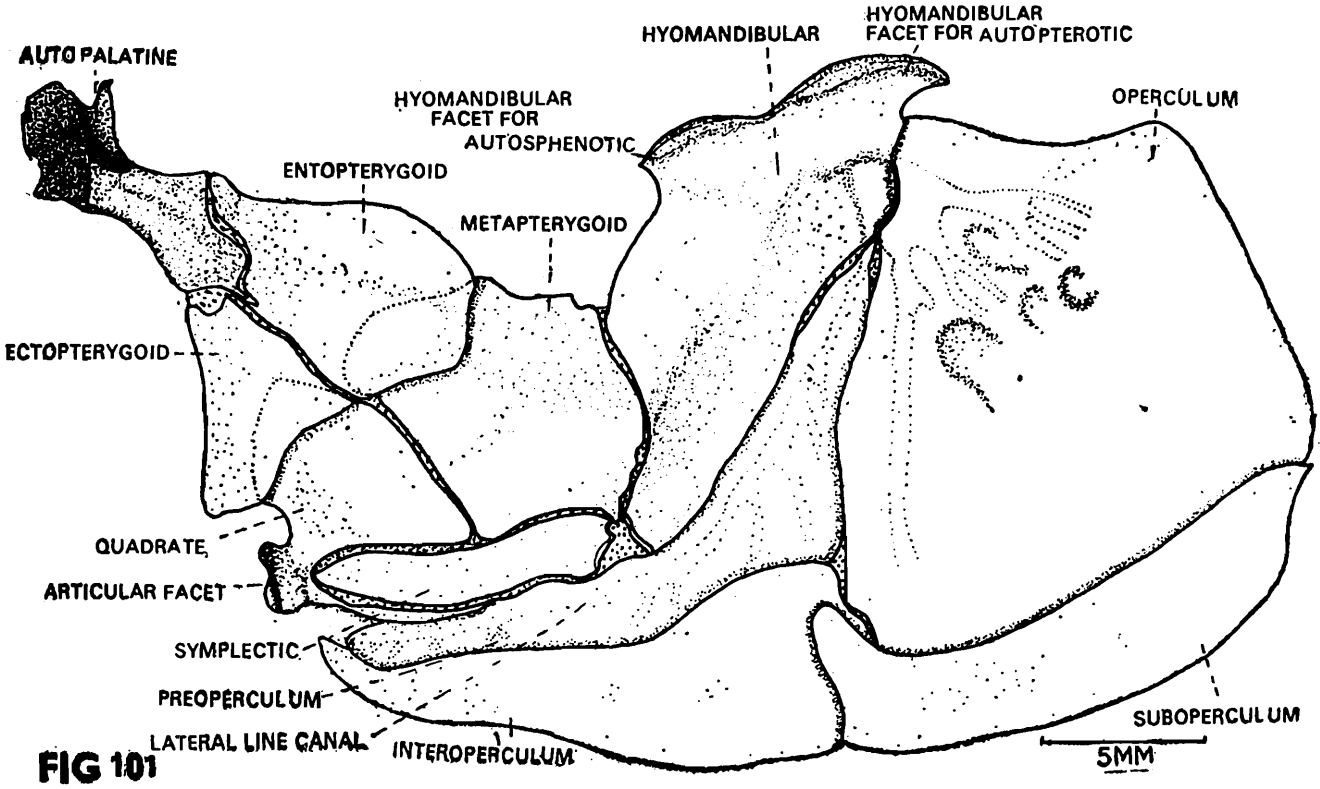


FIG 101

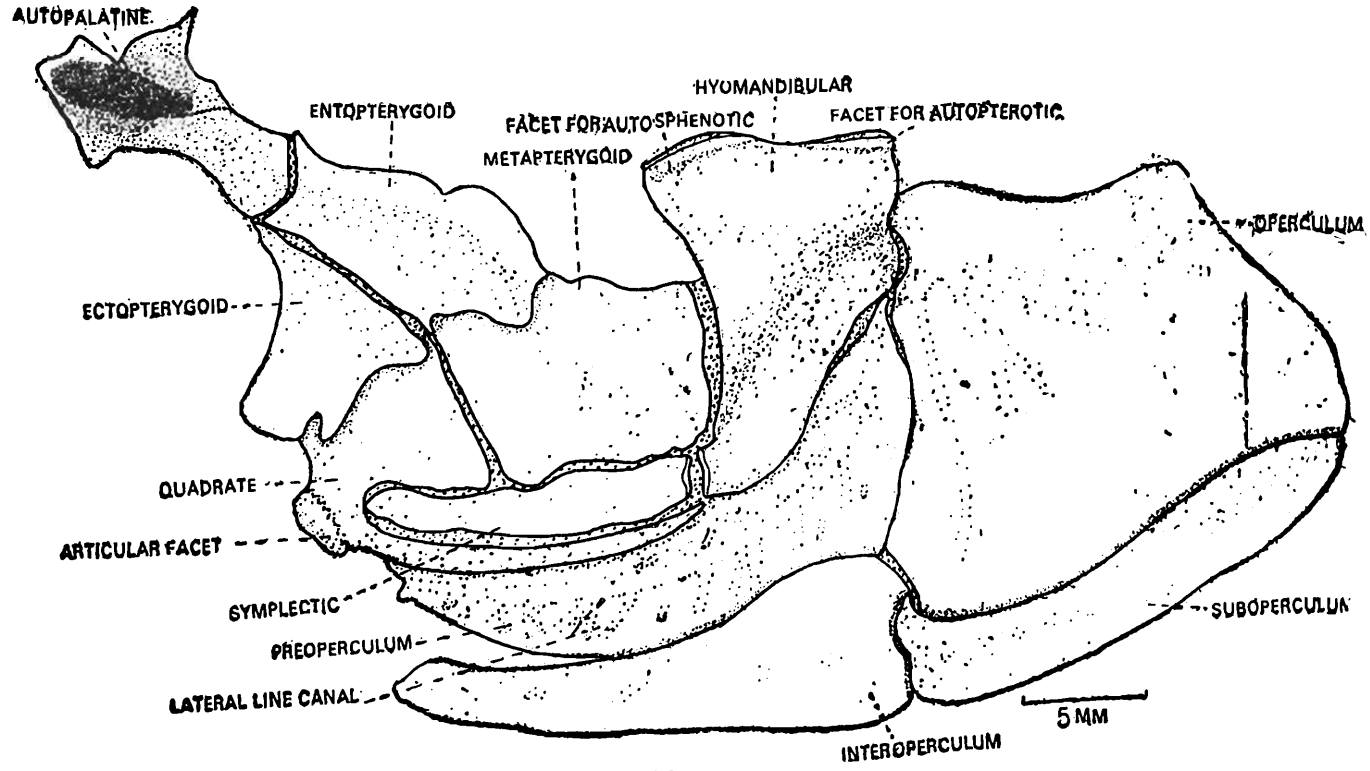


FIG 102

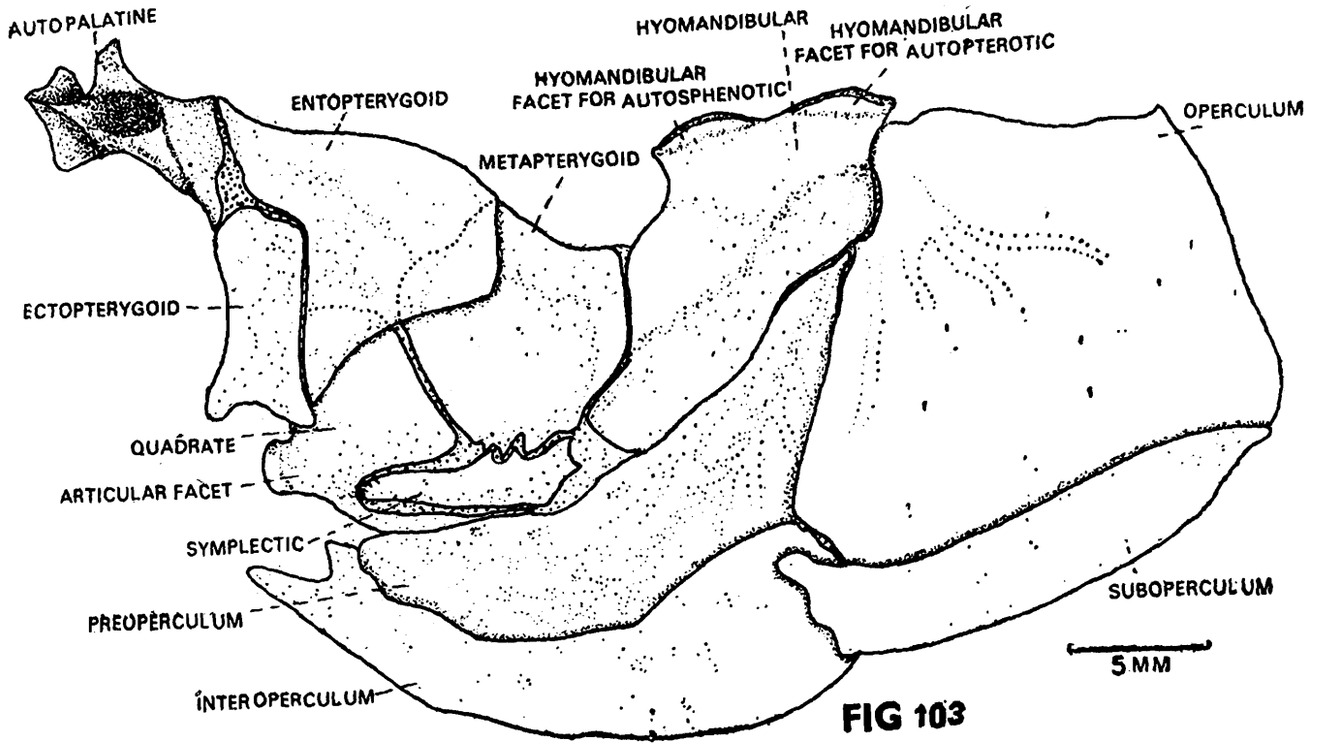


FIG 103

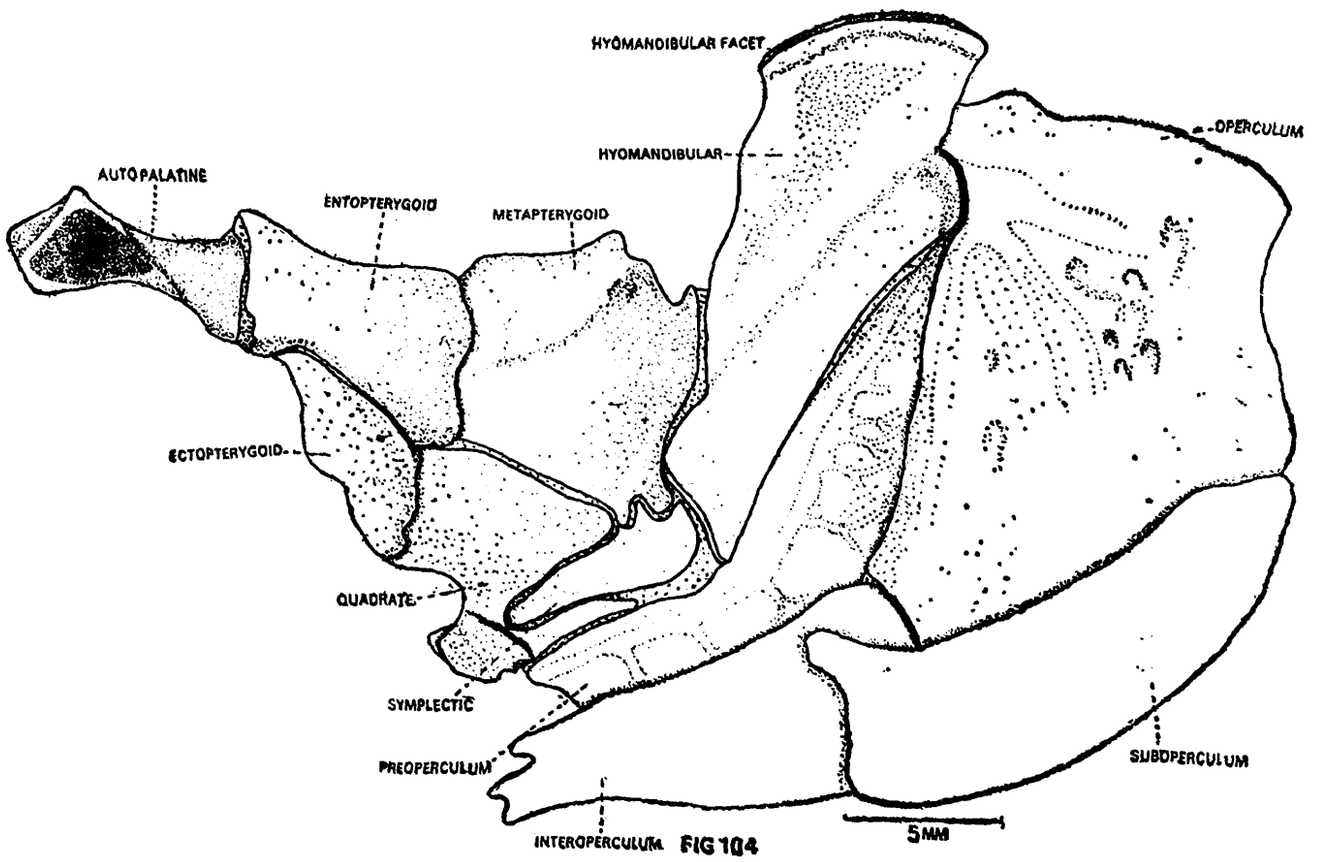


FIG 104

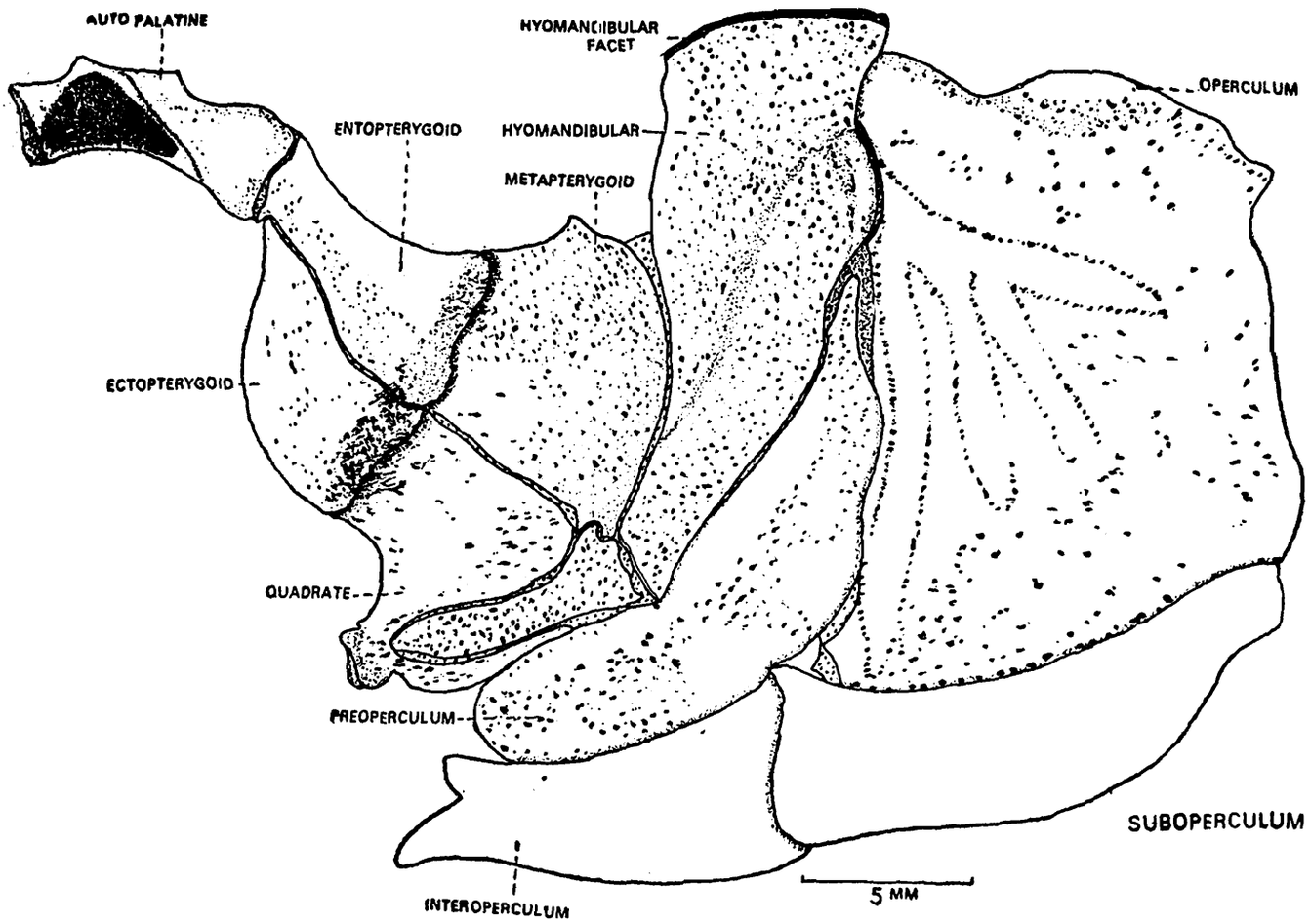


FIG 105

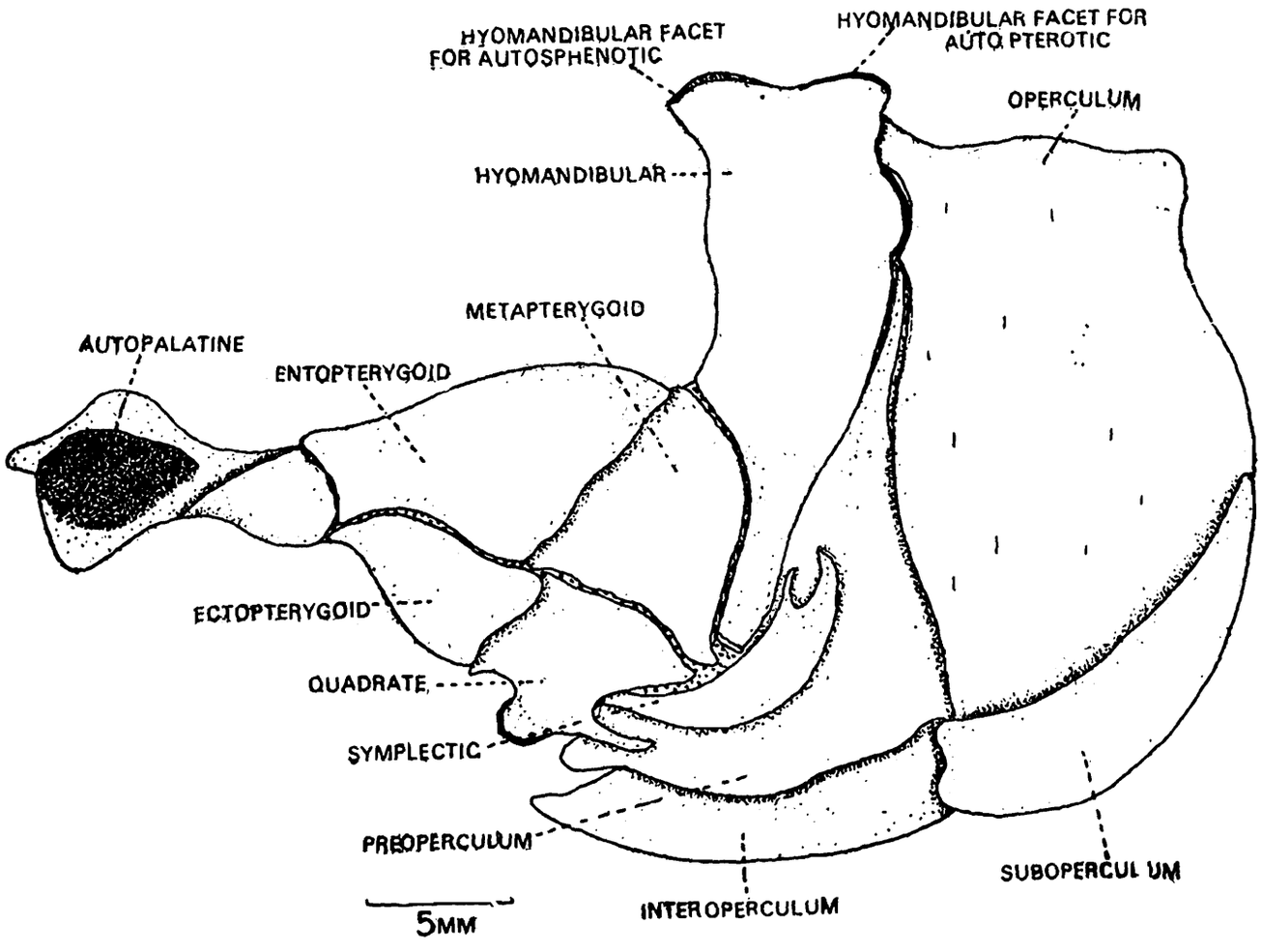


FIG 106

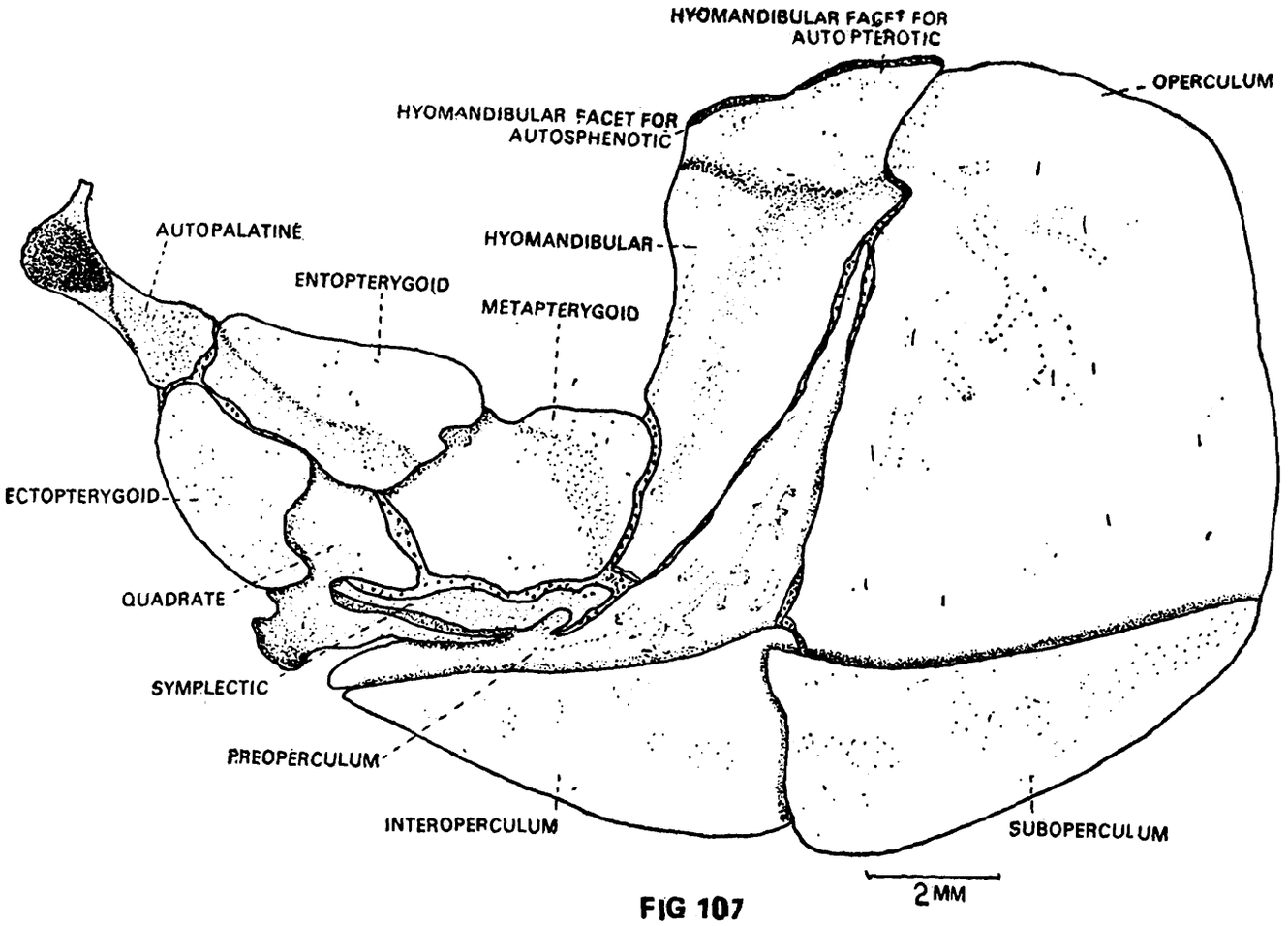


FIG 107

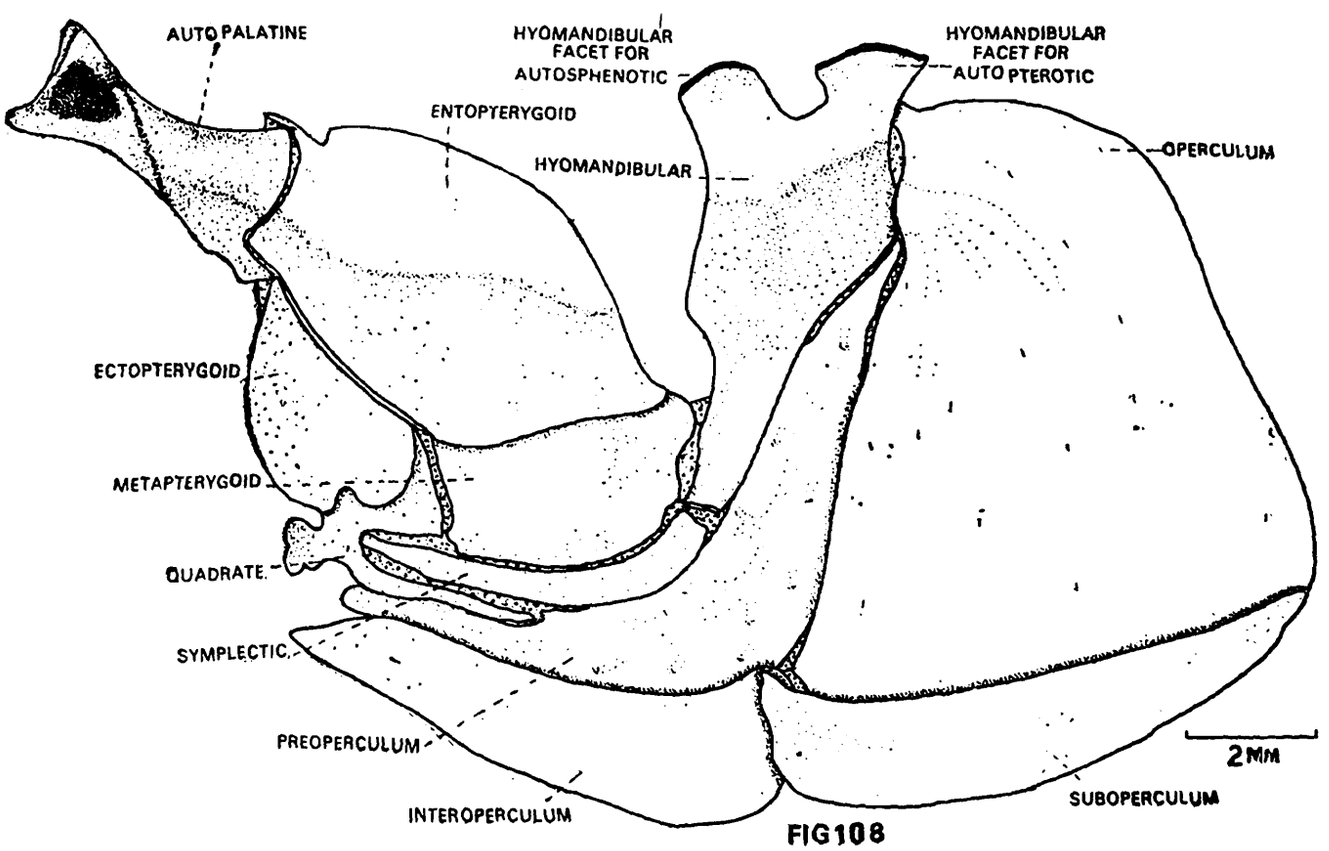


FIG108

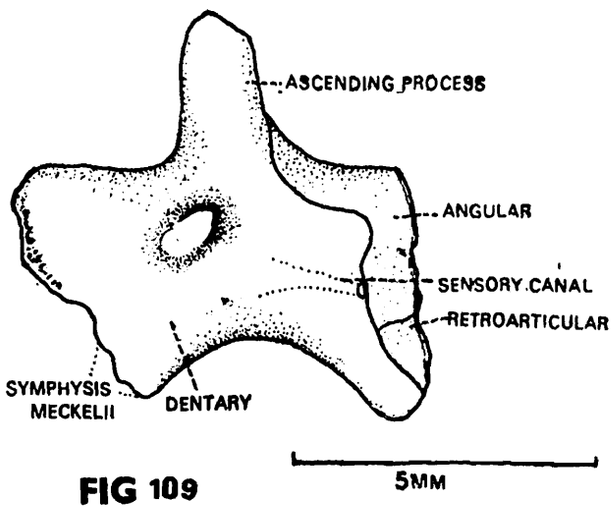


FIG 109

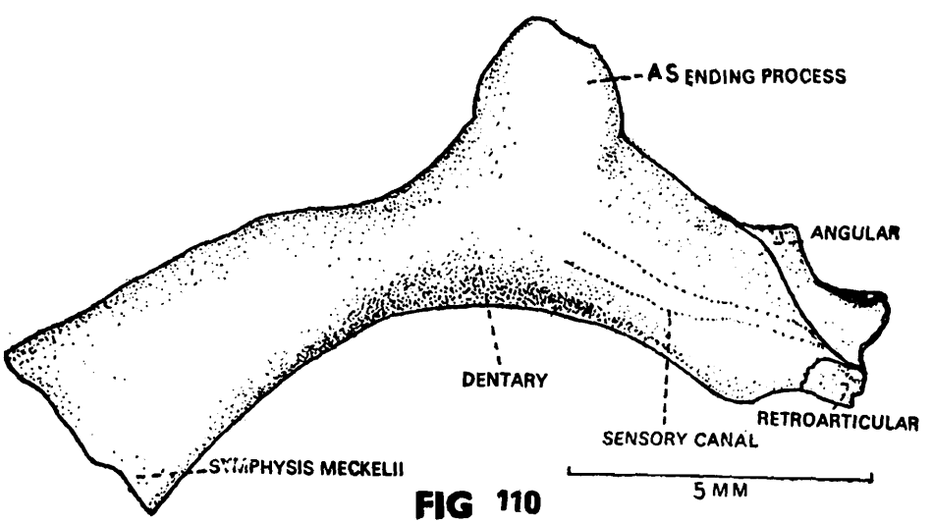


FIG 110

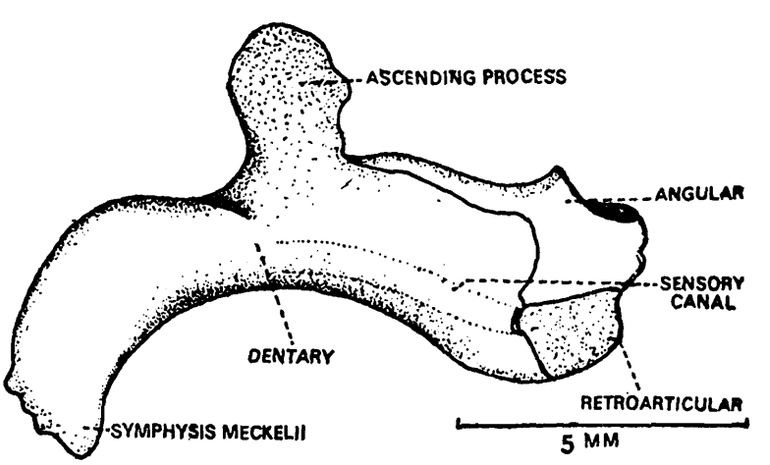


FIG 111

Figs. 109-120. Outer aspects of the left ramus of the lower jaws of *Schizothorax richardsonii*, *Diptychus maculatus*, *Schizopygopsis stoliczkae*, *Ptycobarbus conirostris*, *Schizothoraichthys micropogon*, *S. labiatus*, *Labeo dero*, *Schismatorhynchus nukta*, *Garra lamta*, *Aspidoparia morar* and *Rasbora daniconius* respectively.

Lower jaw : Each mandible is a stoutly built strusture and presents characteristic shape and size. In *Schizothorax richardsonii*, it is short and stumpy while in others, it is elongated except in *Garra lamta* where it is strongly bent in the middle of its length and is inbetween the two cateogories. Each mandibular arch is composed of the dentary, angular,

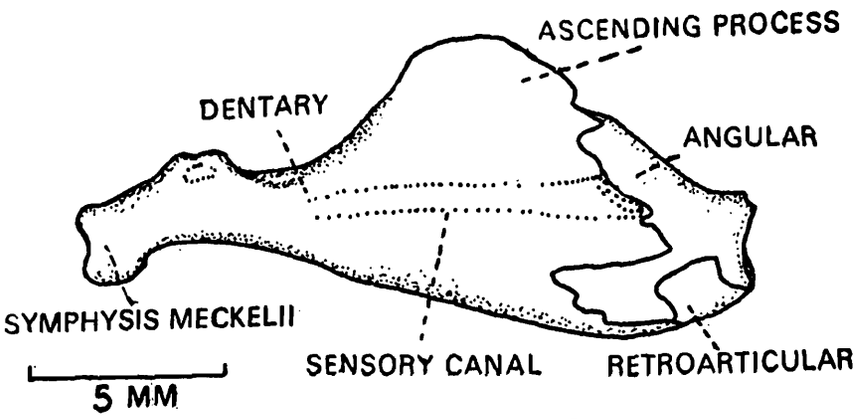


FIG 112

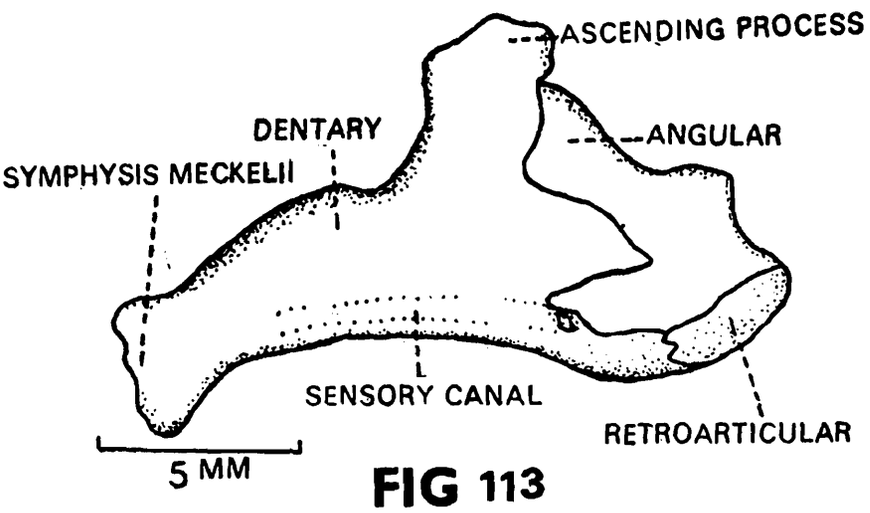


FIG 113

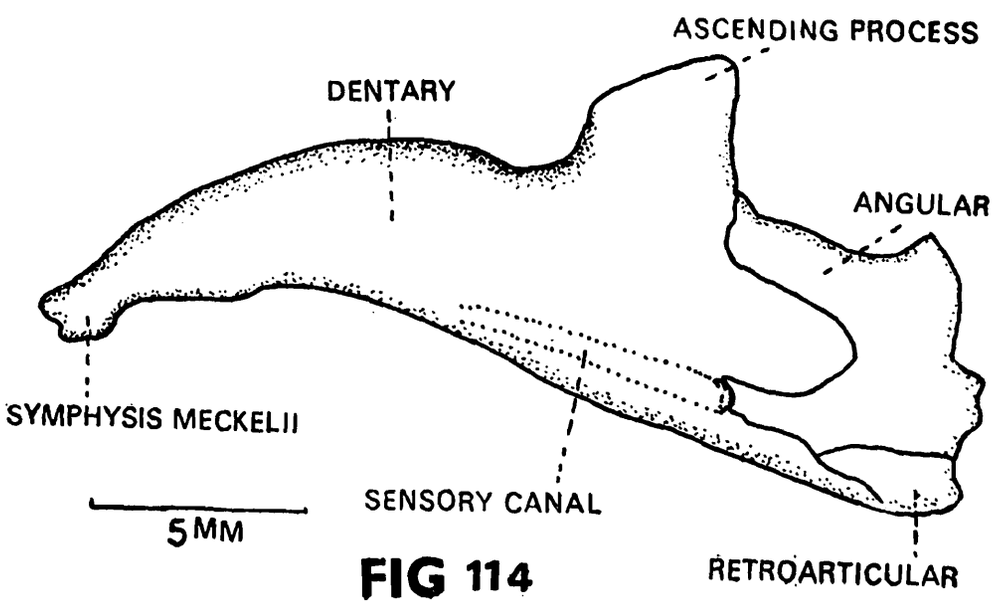


FIG 114

sesamoid articular, the retroaticular and mentomeckelian. These bones are more conspicuous on the lower aspect of each dentay.

Dentary (Figs. 109-132) : It forms the largest part of the mandible bordering the mouth. The dentaries of the two sides articulate medially at the mandibular symphysis. The latter is strong and broad in *Schizothorax richardsoni* and, to a lesser degree, in *Diptychus maculatus*, *Garra lamta*, *Labeo dero* and *Schismatorhyncnus nukta* whereas in rest of the genera under report, the symphysis is smaller in

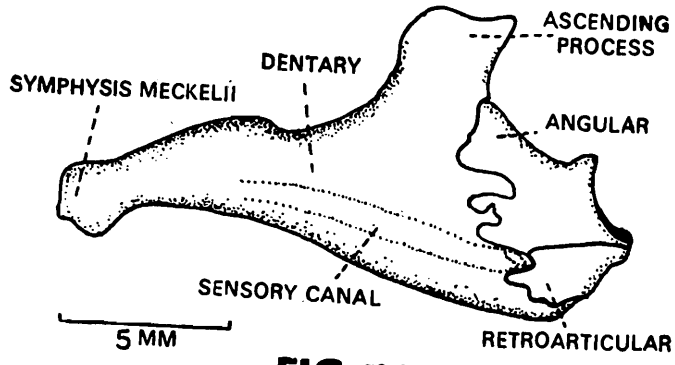


FIG 115

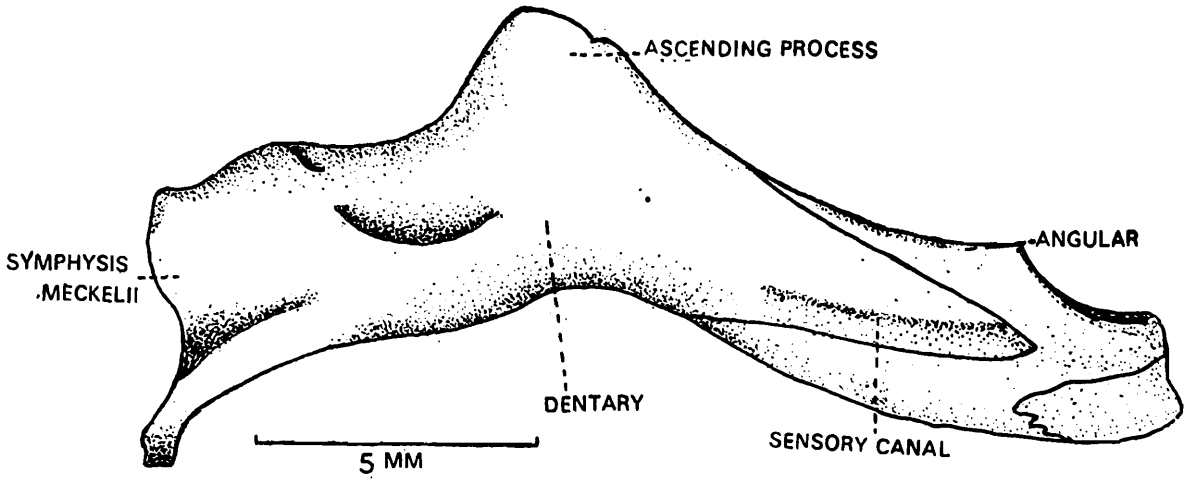


FIG 116

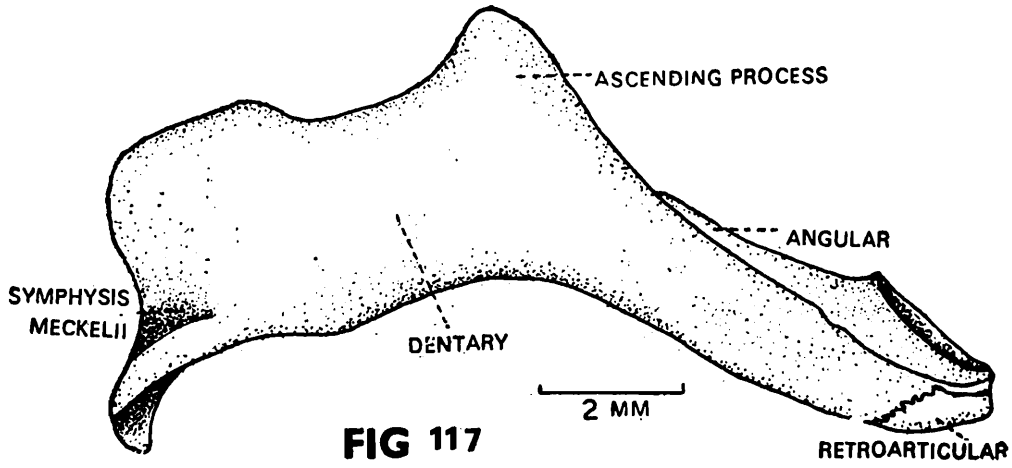


FIG 117

extent. In *labeo dero*, *Schismatorhynchus nukta* and *Aspidoparia morar*, the dentary forms a peculiar posteriorly pointing edge at the lower aspect of the symphysis. In *Garra lamta*, the dentary forms a deep groove on the outer side at its posterior end which provides space for articulation of premaxillaries. Such a groove is absent in all the other species worked out.

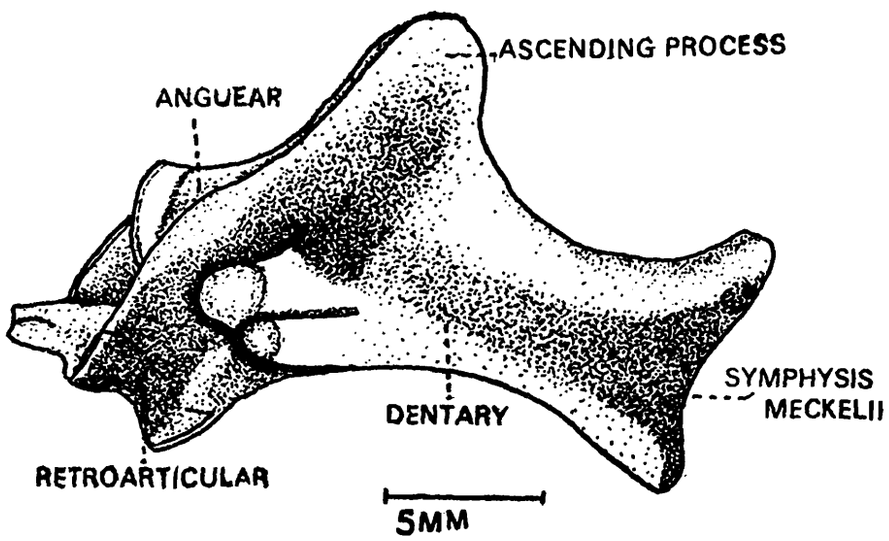


FIG 118

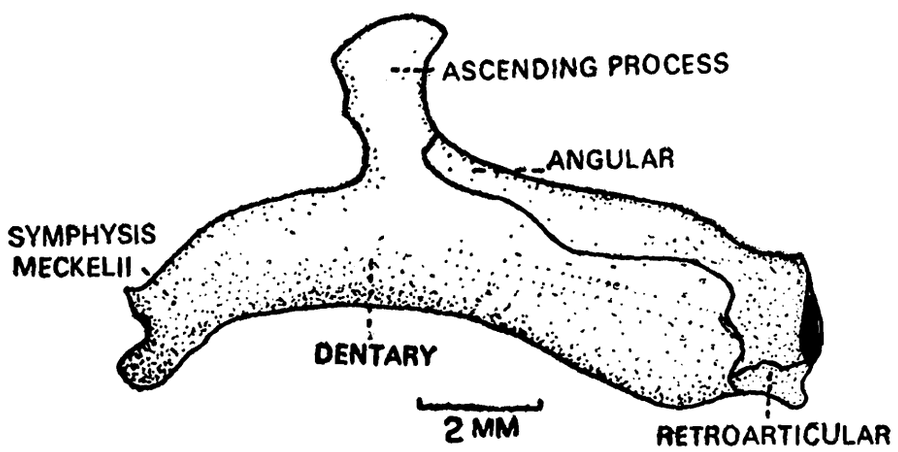


FIG 119

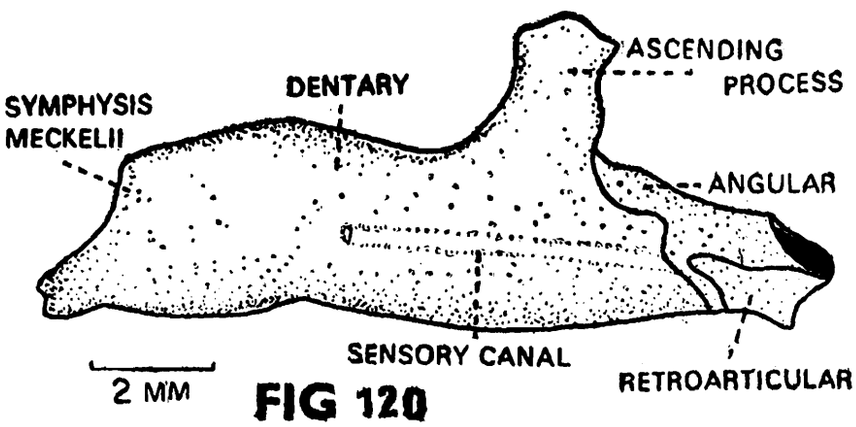


FIG 120

The dentary in each genera has a descending and an ascending limb. The latter has a well pronounced foramen at its base. The ascending process of the dentary is situated almost in the middle of the mandible's

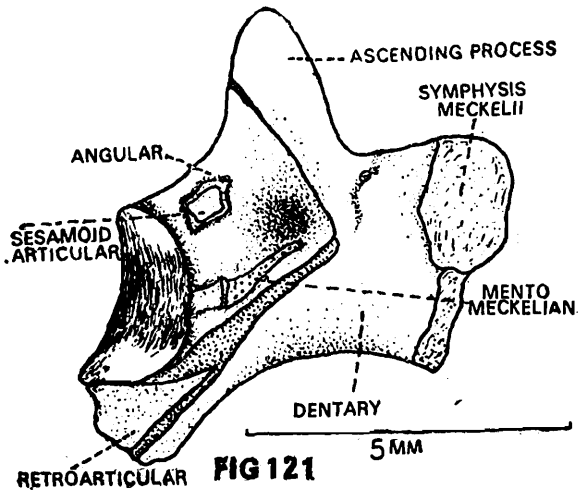


FIG 121

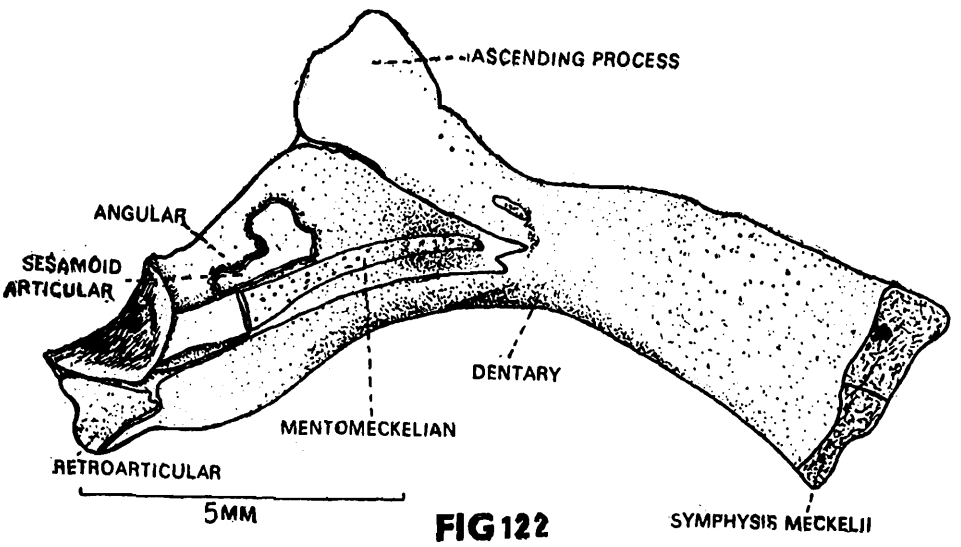


FIG 122

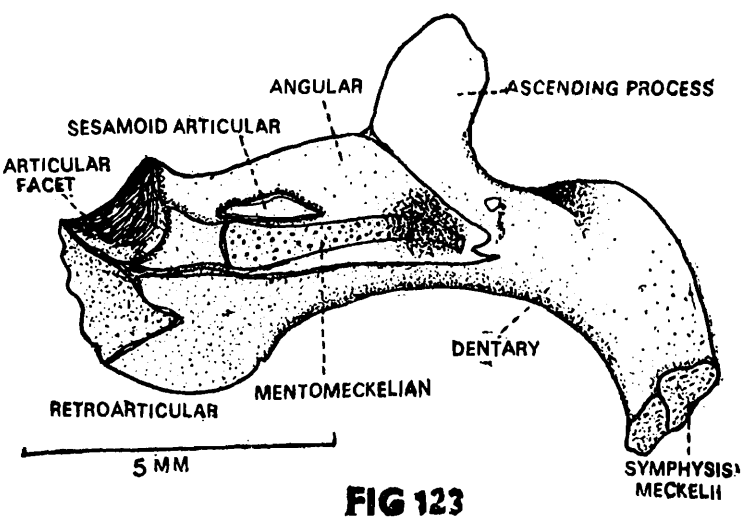


FIG 123

Figs. 121-132. Inner aspects of left ramus of the lower jaws of *Schizothorax richardsonii, Diptychus maculatus, Schizopygosis stoliczkae, Ptycobarbus conirostris, Schizothoraichthys micropogon, S. esocinus S. labiatus, Labeo dero, Schismatorhynchus nukta, Garra lamta, Aspidoparia morar* and *Rasbora daniconius* respectively.

length in *Schizothorax richardsonii*, *Schizopygopsis stoliczkae* and *Ptycobarbus conirostris* while in *Diptychus maculatus*, Schizothoraichthys spp., *Garra lamta* and *Rasbora daniconius*, it is near the posterior than the anterior end of the dentary. In *Labeo dero*, *Schismatorhynchus nukta* and *Aspidoparia morar*, the ascending process is nearer the symphysial end.

The ascending process of the dentary is long and cylindrical in *Schizothorax richardsonii*, *Rasbora daniconius* and *Aspidoparia morar*; broad and wing-like in *Schizopygopsis stoliczkae*; irregularly broad and

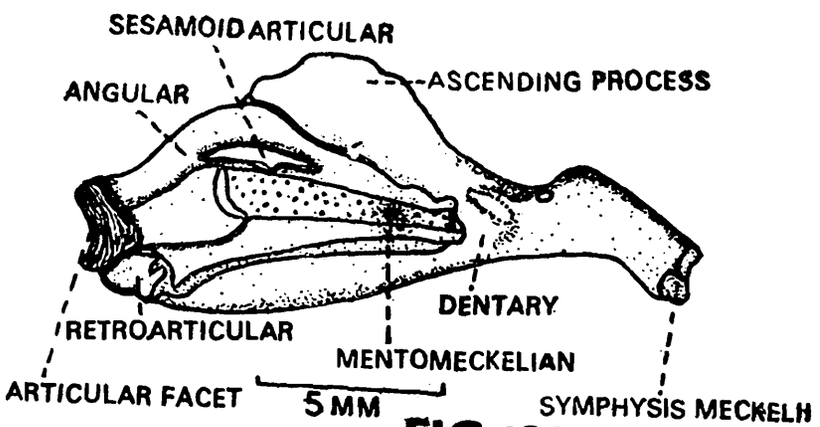


FIG 124

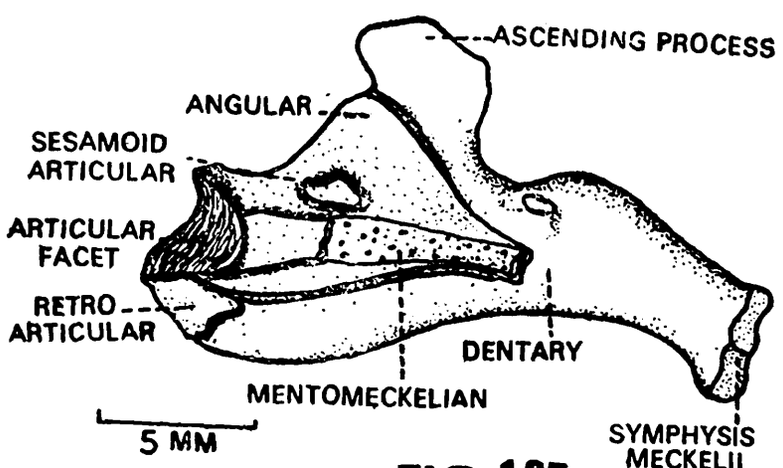


FIG 125

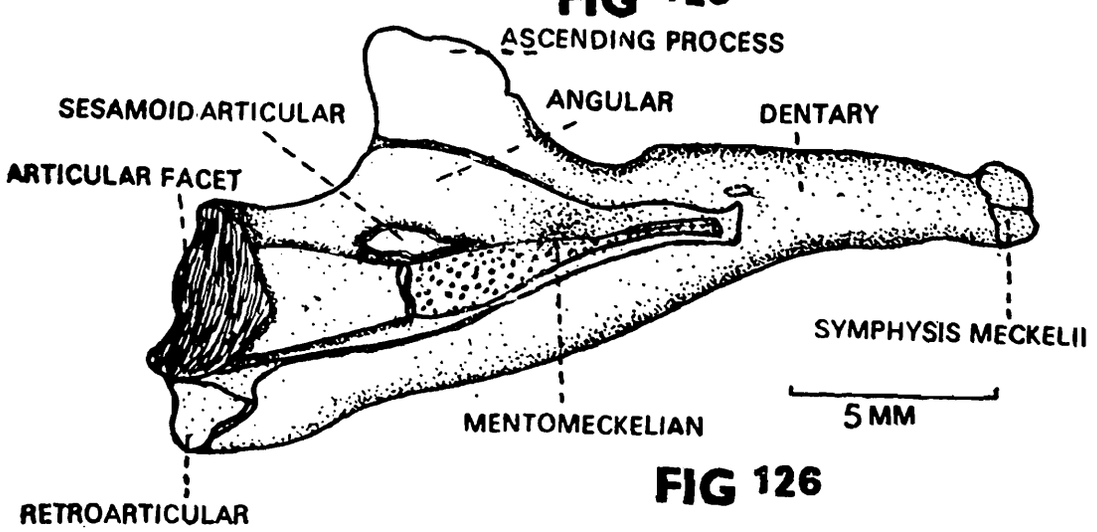


FIG 126

low in *Schizothoraichthys* spp. and *Ptycobarbus conirostris* but in *Labeo dero*, *Garra lamta* and *Schismatorhynchus nukta*, this process is not prominent.

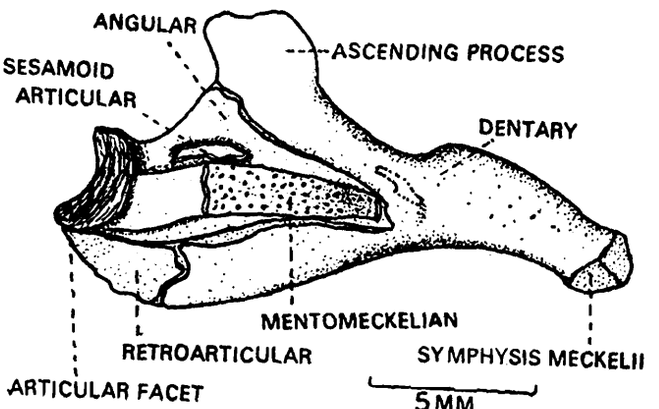


FIG 127

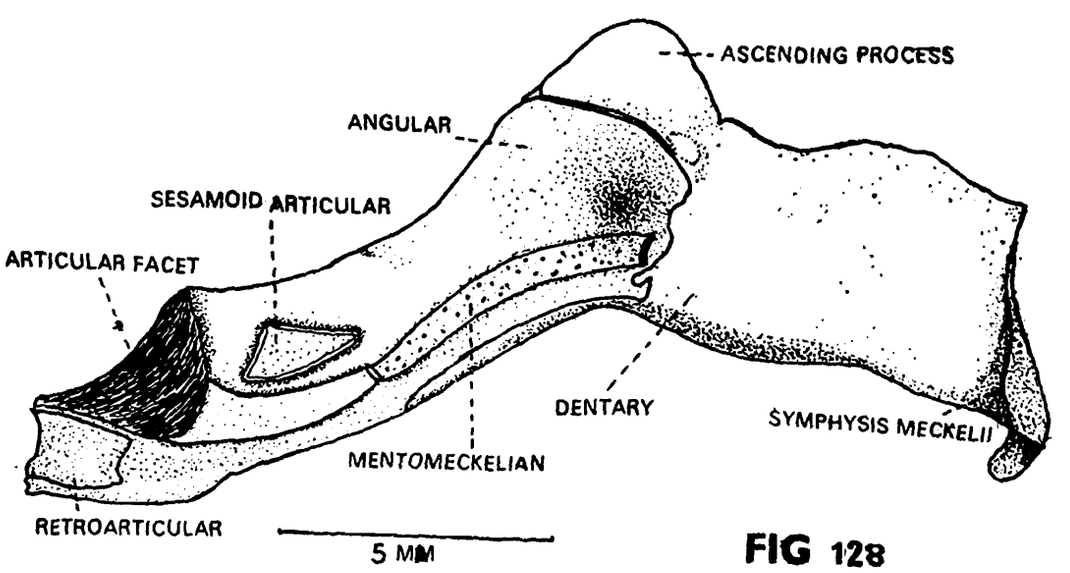


FIG 128

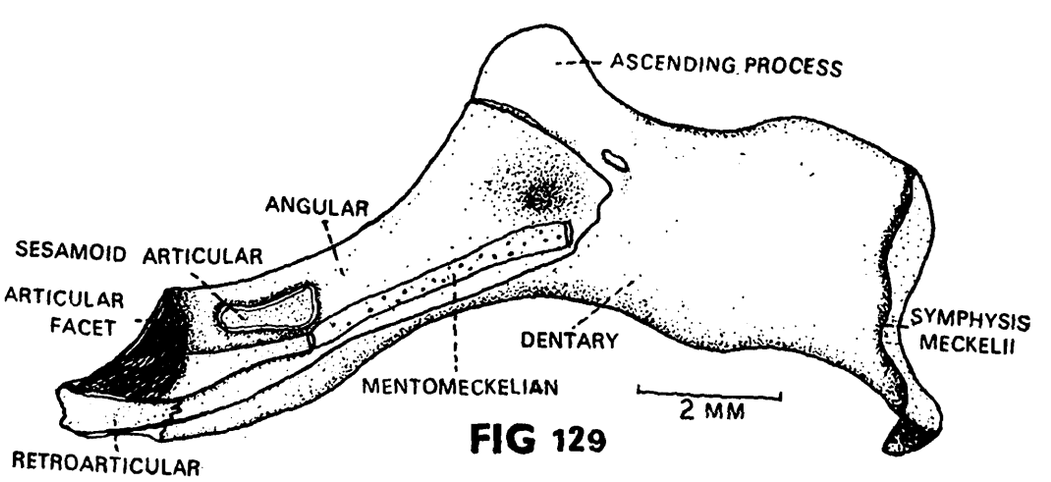


FIG 129

The ascending process of each dentary is movably attached to the premaxillary and maxillary through ligaments so that with the depression of the lower jaw, the ascending process of the dentary

moves forward and downwards carrying with it the posterior end of maxillaries. It is a toothless bone and encloses the mandibular canal.

Angular (Figs. 121-132) : The angular is a large bone at the posterior border of which is found an articular facet ; on the mesial aspect of the mandible, there is a deep depression which is much pronounced in *Schizothorax richardsonii*, *Garra lamta* and *Diptychus maculatus* than in the rest of the species studied.

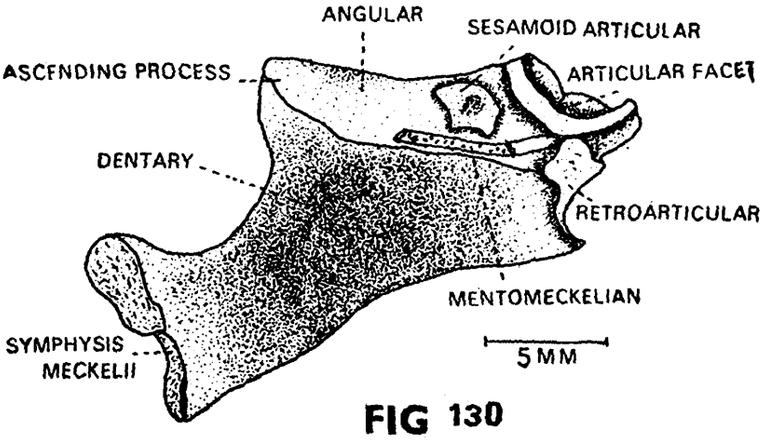


FIG 130

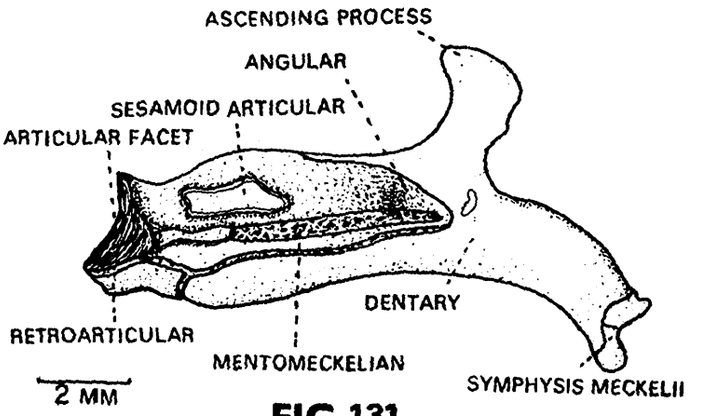


FIG 131

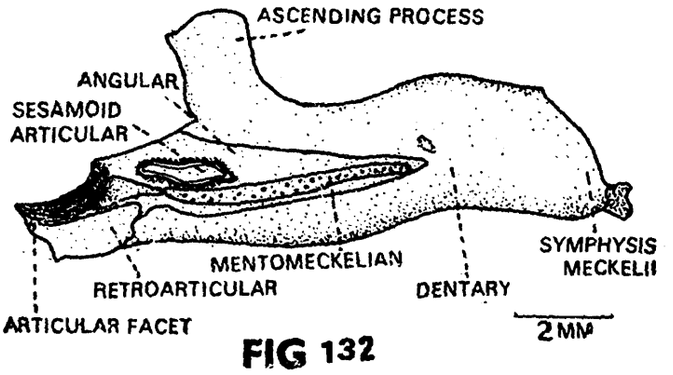


FIG 132

Sesamoid articular (Figs. 121-132) : It is a small bone attached on the mesial aspect of the angular, just above the mentomeckelian. It can easily be dislodged from its position. This bone is short and stumpy in *Schizothorax richardsonii* while it is elongated in others.

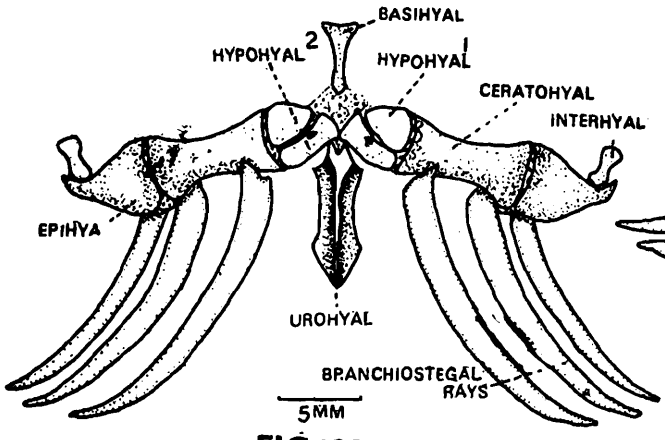


FIG 133

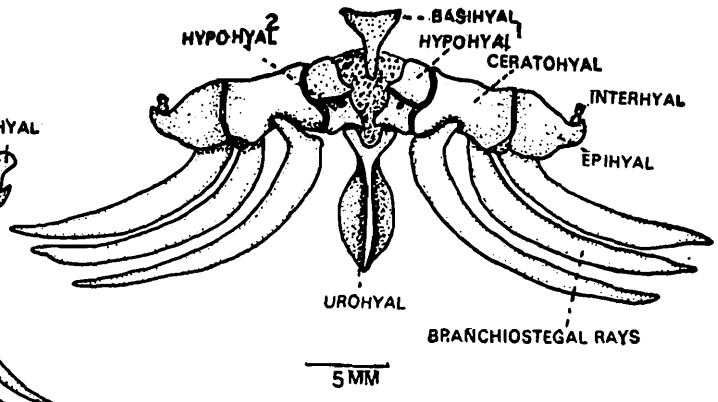


FIG 134

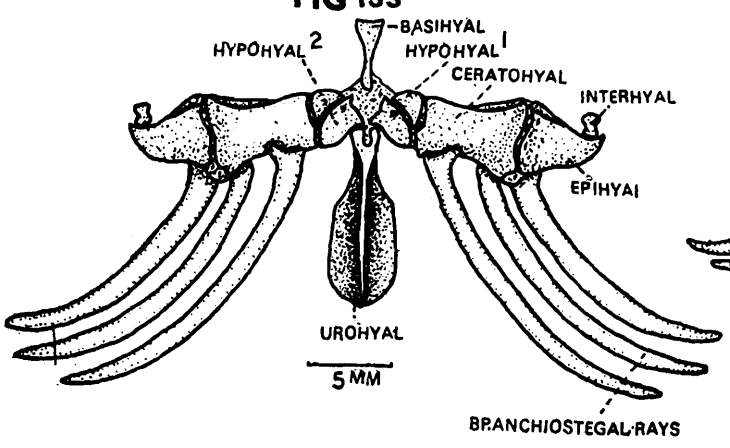


FIG 135

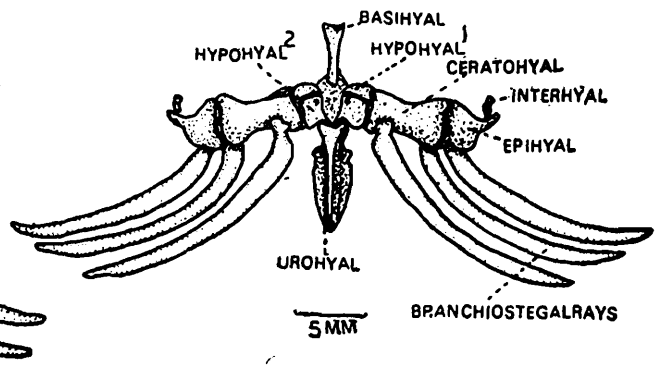


FIG 136

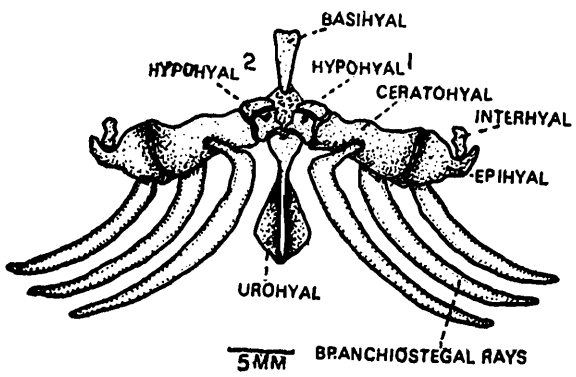


FIG 137

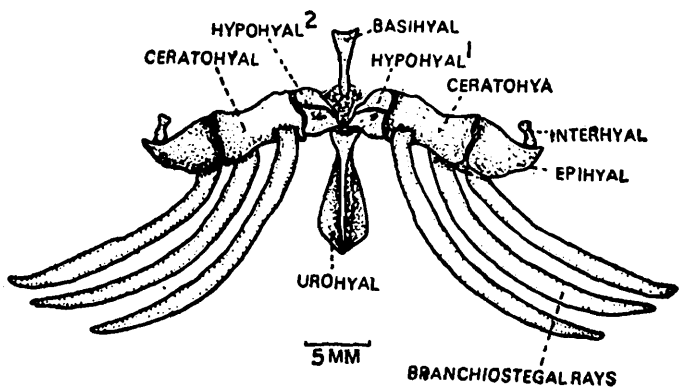


FIG 138

Figs. 133-144. Dorsal aspects of the hyoid arches and urohyal of *Schizothorax richardsonii, Diptychus maculatus, Schizopygopsis stoliczkae, Ptycobarbus conirostris, Schizothoraichthys micropogon, S. esocinus S. labiatus, Labeo dero, Schismatorhynchus nukta, Rasbora daniconius, Aspidoparia morar* and *Garra lamta* respectively.

Retroarticular (Figs. 109-132) : it is a small, splint-like bone, embedded at the posterior tip of the angular below the articular facet. Significant variation is not seen in the structure of this bone.

Mentomeckelian (Figs. 121-132) : It is a rod-like bone attached to the mesial surface of the angular. Due to the lengthening of the mandible, the corresponding length of the mentomeckelian is also increased.

(ii) *Hyobranchial region* :

In fishes, the visceral arches are differentiated into the mandibular, the hyoid and the branchial arches. The mandibular arch gets resolved into the mandibles while the hyoid arch and the branchial arches (3-7) jointly support the hyobranchial apparatus which subserves mainly the function of respiration and partly helps in feeding by straining the food material from water. The hyoid arch (2) is in close association with the branchial arches and therefore, it should be pertinent to describe the hyoid and branchial arches together.

Hyoid arch : Each half of the hyoid arch, as in the teleostean fishes in general, is divisible into the dorsal hyomandibular part which forms the suspensorium and the ventral hyoid cornua.

Suspensorium : It is formed by two bones, the hyomandibular and the symplectic.

Hyomandibular (Figs. 85-108) : It is a long, thick, flat bone lying in an obliquely vertical position between the auditory capsule above and the preoperculum below. The dorsal edge of each hyomandibular bears at its upper end either one articular facet as in *Labeo dero* and *Schismatorhynchus nukta* or two articular facets as in all the other genera under report. In the latter case, the anterior articular facet is smaller in length than the posterior one and fits into a groove formed mainly by the autosphenotic. Sometimes, a small portion of prootic also shares the formation of anterior groove. The groove for the posterior articular facet is formed by the autopterotic (2/3rd) and autosphenotic (1/3rd). However, in *Rasbora daniconius*, the groove for posterior articular facet is formed only by autopterotic. The two articular facets of hyomandibular are narrowly separated from each other except in *Rasbora daniconius* where the two facets are widely separated from each other through a deep depression between them. In *Labeo dero* and *Schismatorhynchus nukta*, the single, large articular facet of hyomandibular fits into a groove shared equally by autopterotic and autosphenotic.

The hyomandibular articulates anteriorly with the metapterygoid, posteriorly with the preoperculum and the operculum and ventrally with the symplectic. On its posterior border, the hyomandibular bears

an articular concavity for the attachment of operculum and on its ventral side, it bears a shallow groove for the passage of facial nerve.

Symplectic (Figs. 85-108) : It is a small bone, lying embedded in cartilage inbetween the quadrate, metapterygoid, preoperculum and the hyomandibular. Its anterior end fits into a groove on the posterior extension of the quadrate. It is connected to hyoid arch through the interhyal. The symplectic is a small and stout bone in *Schizothorax richardsonii* and *Garra lamta* while it is long and rod-like in other genera under report. The symplectic is oriented ventrally in the schizothoracine and rasborine genera while in cyprinine genera, it is oriented ventrolaterally.

Hyoid cornua : The hyoid cornua comprises paired interhyals, epihyals and the unpaired basihyal. An additional, median urohyal is attached behind the point of union of the hypohyals of two sides.

Interhyal (Figs. 133-144) : It is a small, spicule-like bone which lies in a hook formed at the dorsoposterior side of the epihyal. On the other side, it is attached to the strip of cartilage near the symplectic. Little variation is seen in this bone in the genera under report.

Epihyal (Figs. 133-144) : It is a flat and stout bone whose anterior end is broad and posterior one is narraw and tappering. Its anterior end articulates with the broad posterior end of ceratohyal. On its anteroventral side, a branchiostegal ray is attached. Each epihyal is attached to the inner mesial side of interoperculum.

Ceratohyal (Figs. 133-144) : It articulates anteriorly with a pair of hypohyals and bears two branchiostegal rays, one on the anteroventral and the other on the posteroventral side. It is a long rectangular bone in schizothoracine and rasborine genera. In cyprinine representatives, it is slightly longer.

Hypohyals (Figs. 133-144) : Both the hypohyals of each side are stout and stumpy bones which rest against each other so closely that distinction between them is rather difficult. The medial ends of hypohyals of two sides enclose between them the posterior end of basihyal. Variations are seen in the relative size of the two hypohyals. The dorsal hypohyal is smaller than the ventral one in *Schizothorax richardsonii*, *Schizopygopsis stoliczkae*, *Ptycobarbus conirostris*, *Schizothoraichtys* spp., *Labeo dero*, *Schismatorhynchus nukta* and *Rasbora daniconius*. They are equal in size in *Garra lamta* and *Aspidoparia morar* while the ventral element is smaller than the dorsal one in *Diptychus maculatus*.

Basihyal (Figs. 133-144) : The basihyal is a median, bony element which is free at its anterior side ; posterolaterally, it is closely attached

to the hypohyals whereas posteriorly, to the anterior end of first basibranchial.

The shape and size of the basihyal differ in different genera. It is cup-like in *Schizothorax richardsonii*; funnel-shaped in *Diptychus maculatus* and roughly triangular in *Labeo dero*. It is flask-shaped in *Schismatorhynchus nukta* while rod-like in rest of the species under report.

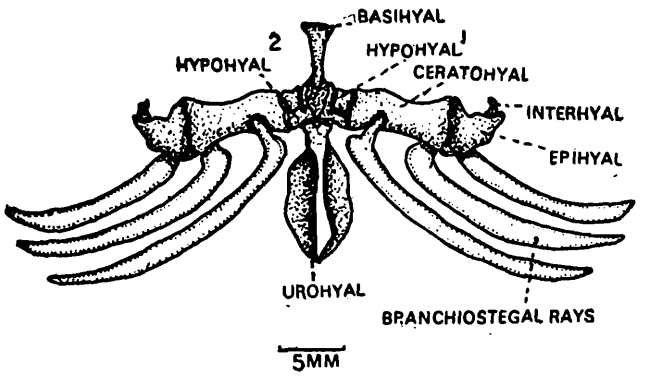


FIG 139

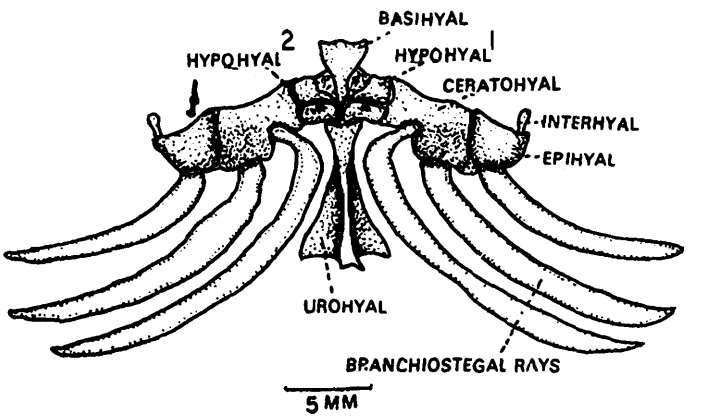


FIG 140

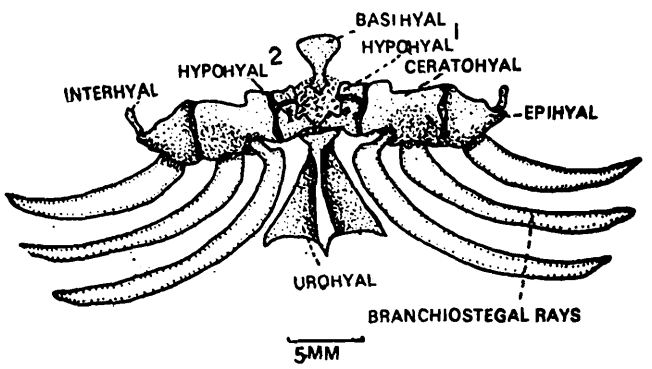


FIG 141

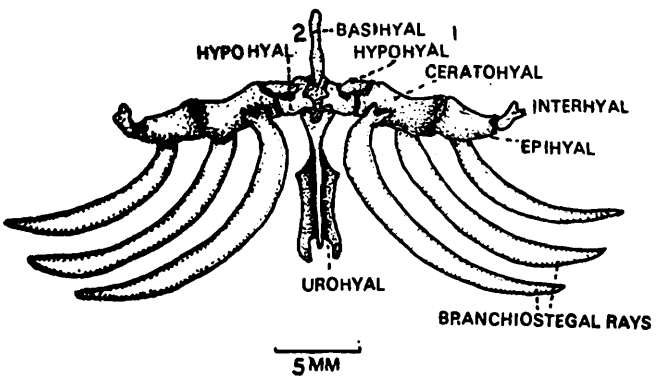


FIG 142

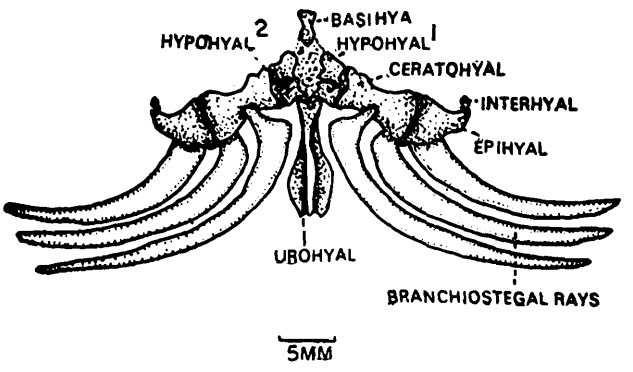


FIG 143

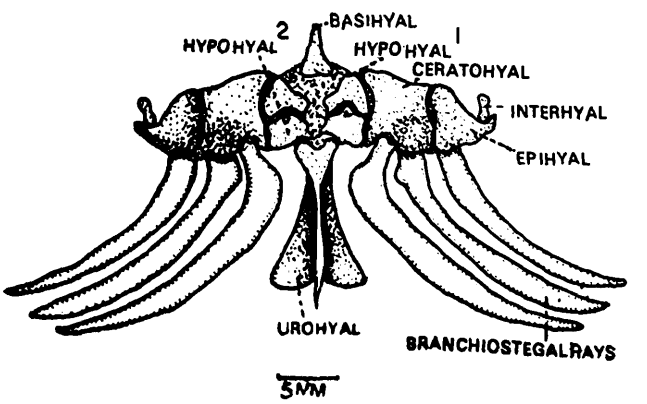
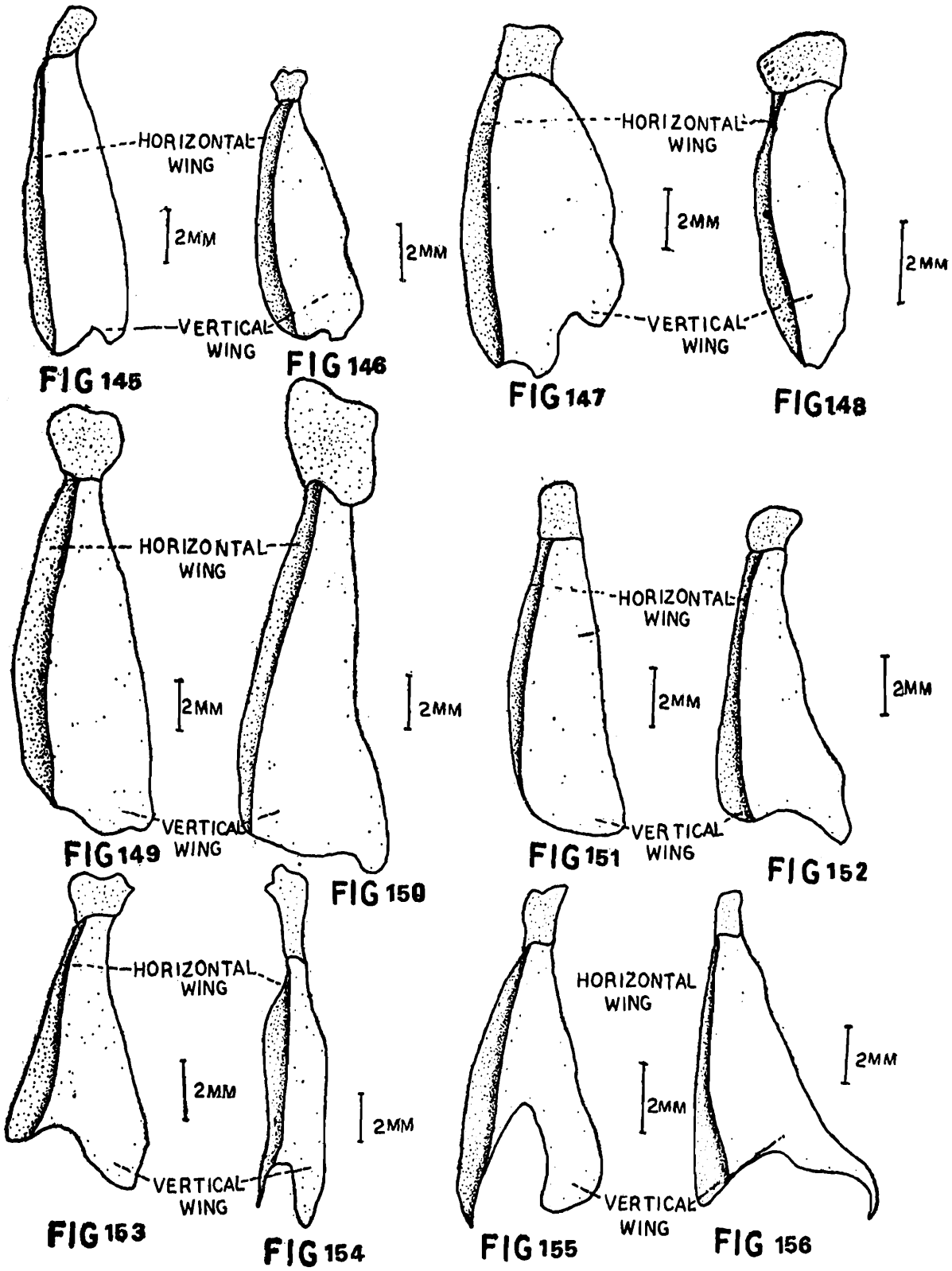


FIG 144

Urohyal (Figs. 133-156) : It lies posterior to the basihyal along the midventral line. In all the species studied, the urohyal has two ventral wings of the bone which lie almost in a horizontal plane. The third median wing lies almost at right angles to the two ventral wings. The



Figs. 145-156. Lateral aspects of urohyals of *Schizothorax richardsonii, Diptychus maculatus, Schizopygopsis stoliczkae, Ptycobarbus conirostris, Schizothoraichthys micropogon, S. esocinus, S. labiatus. labeo dero, Schismatorhynchus nukta, Rasbora daniconius, Aspidoparia morar* and *Garra lamta* respectively.

shape of the bone differs in all the genera reported. The median vertical wing is slightly shorter than the basal horizontal wings in *Schizothorax richardsonii*, *Diptychus maculatus*, *Schizopygopsis stoliczkae* and *Rasbora daniconius*. It extends beyond the body of the basal wings in *Schizothoraichthys* spp., *Labeo dero*, *Schismatorhynchus nukta* and *Garra lamta* while it is almost equal to the length of basal wings in *Ptycobarbus conirostris* and *Aspidoparia morar*.

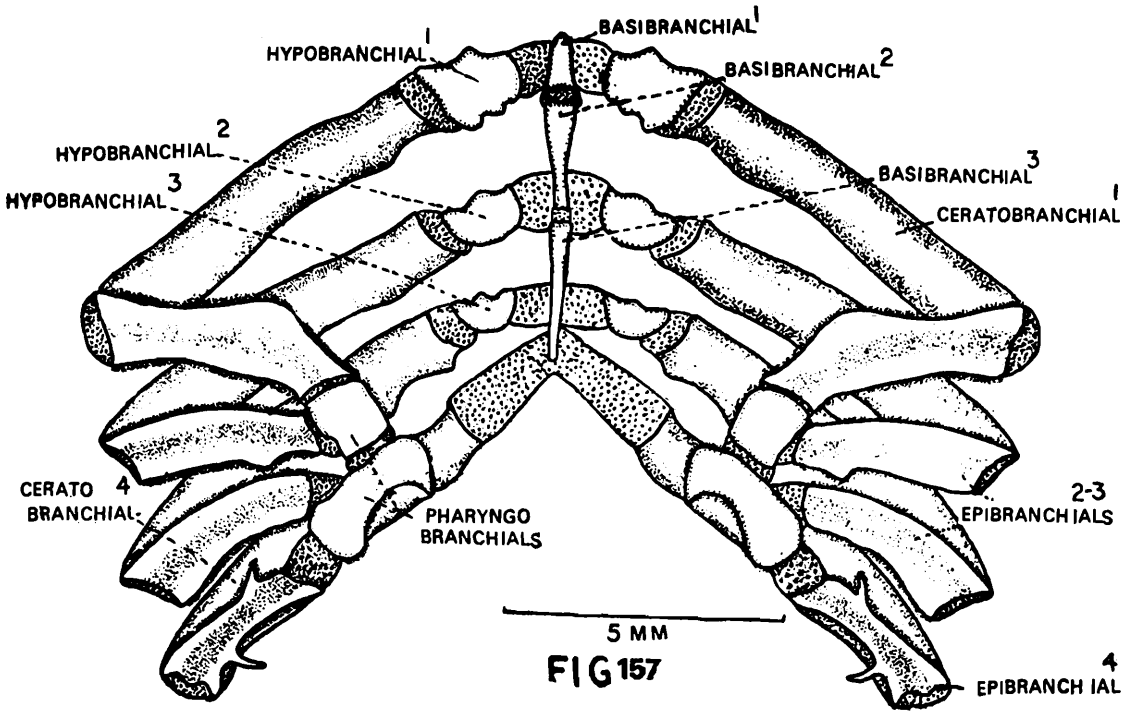
The anterior end of the urohyal bears an articular facet through which it has a ligamentous connection with the posterior end of the basihyal while it articulates directly with the ventral hypohyals of two sides.

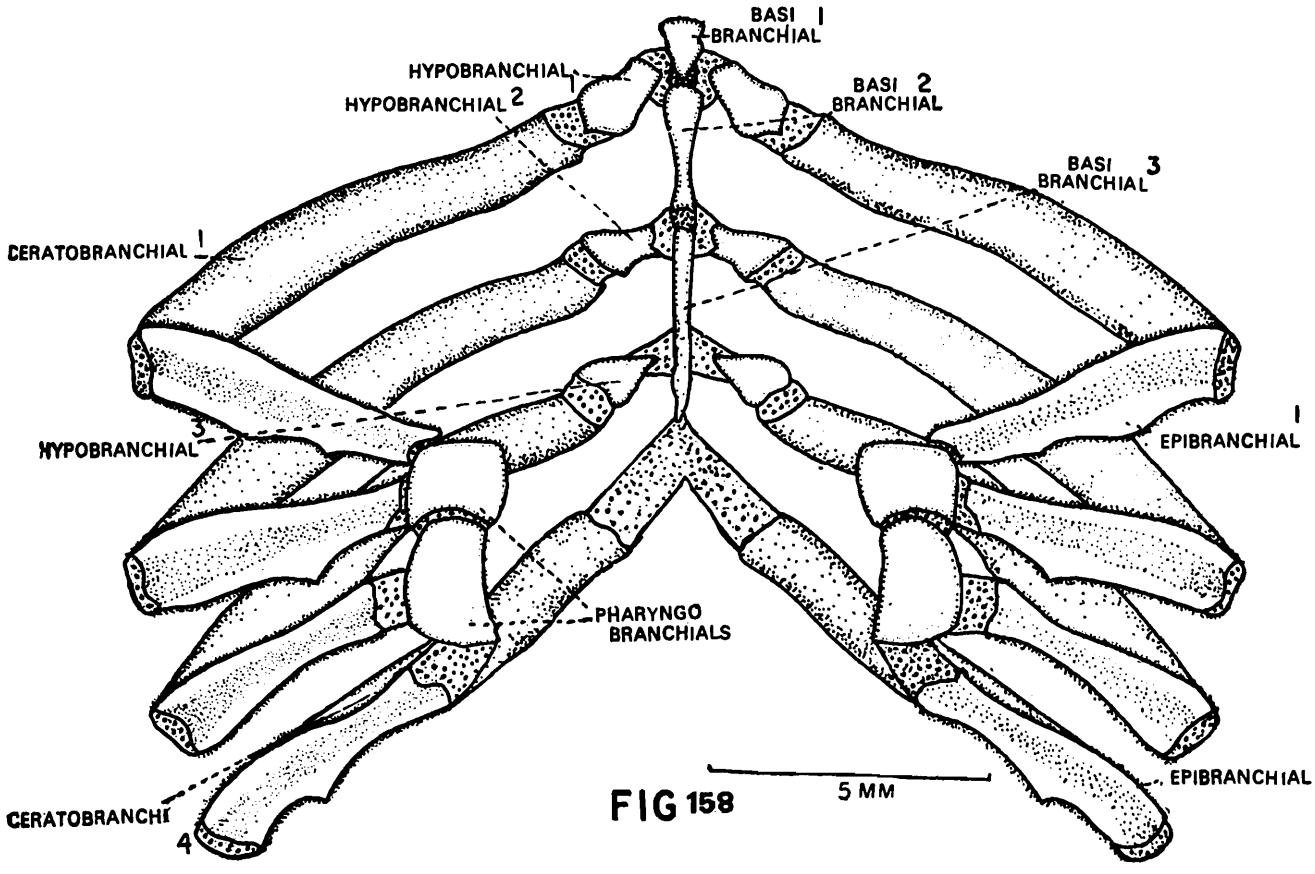
Branchial arches : Of the five pairs of branchial arches, the first four support the gills and the wall of the pharynx and the fifth constitutes the inferior pharyngeal bone. Each branchial arch has ossified, replacing bones which are respectively the pharyngobranchial, the epibranchial, the ceratobranchial, the hypobranchial and the median basibranchial. The fifth gill arch is represented by the ceratobranchial alone.

Pharyngobranchials (Figs. 157-168) : These are small pieces of bones lying obliquely in the dorsal wall of the pharynx. There are two pharyngobranchials on each side which are connected dorsally to the auditory capsule by ligaments and ventrally, to the posterior ends of the epibranchials.

The first pharyngobranchial is a small, rectangular piece which shows the attachment to the first two epibranchials by small cartilaginous piece in between them thus showing that this piece represents two fused pharyngobranchials. The second one is large, deeply curved structure bearing third and fourth epibranchials, thus showing two fused pharyngobranchials as noticed in each species studied.

Epibranchials (Figs. 157-168) : They are obliquely curved rods, on either side of the pharynx, attached between the pharyngobranchials and the ceratobranchials ; posteriorly, they are directed outwards and backwards. They are elongated and deeply grooved along their inner and ventral margins. Each groove also receives the branchial artety, flanked by two rows of gill filaments along their length. Two rows of small, bony gill rakers are present on the dorsal surface of each epibranchial. The first two epibranchials in all the genera are broader and the third and fourth are thinner. The third one bears a small projection on its posterolateral margin in *Ptycobarbus conirostris*, *Schizothoraichthys micropogon*, *Schizothoraichthys esocinus*, *Labeo dero*, *Garra lamta* and *Schismatorhynchus nukta* which is not seen in any other genera.





Figs. 157-168. Dorsal aspects of branchial baskets of *Schizothorax richardsonii*, *Diptychus maculatus*, *Schizopygopsis stoliczkae*, *Ptycobarbus conirostris*, *Schizothoraichthys micropogon*, *S. esocinus*, *S. labiatus* *Labeo dero*, *Schismatorhynchus nukta*, *Rsbora daniconius*, *Aspidoparia morar* and *Garra lamta* respectively.

Ceratobranchials (Figs. 157-168) : They are elongated, rod-like bones situated between the epibranchials and hypobranchials of each side and lie at the base of the basket. They are of similar shape and decrease

slightly in length from first to fourth. Ventrally, each ceratobranchial is grooved and into this groove runs the branchial artery, flanked by two rows of gill filaments. On its dorsal side, there are present two rows of small, long gill rakers.

Hypobranchials (Figs. 157-168) : First three branchial arches bear the hypobranchials. Each of the first hypobranchial is a small piece, articulating anteriorly with the anterolateral edge of the first basibranchial, posteriorly, with the anterior portion of the first ceratobranchial and anterodorsally, with the hypohyals. All these artculations

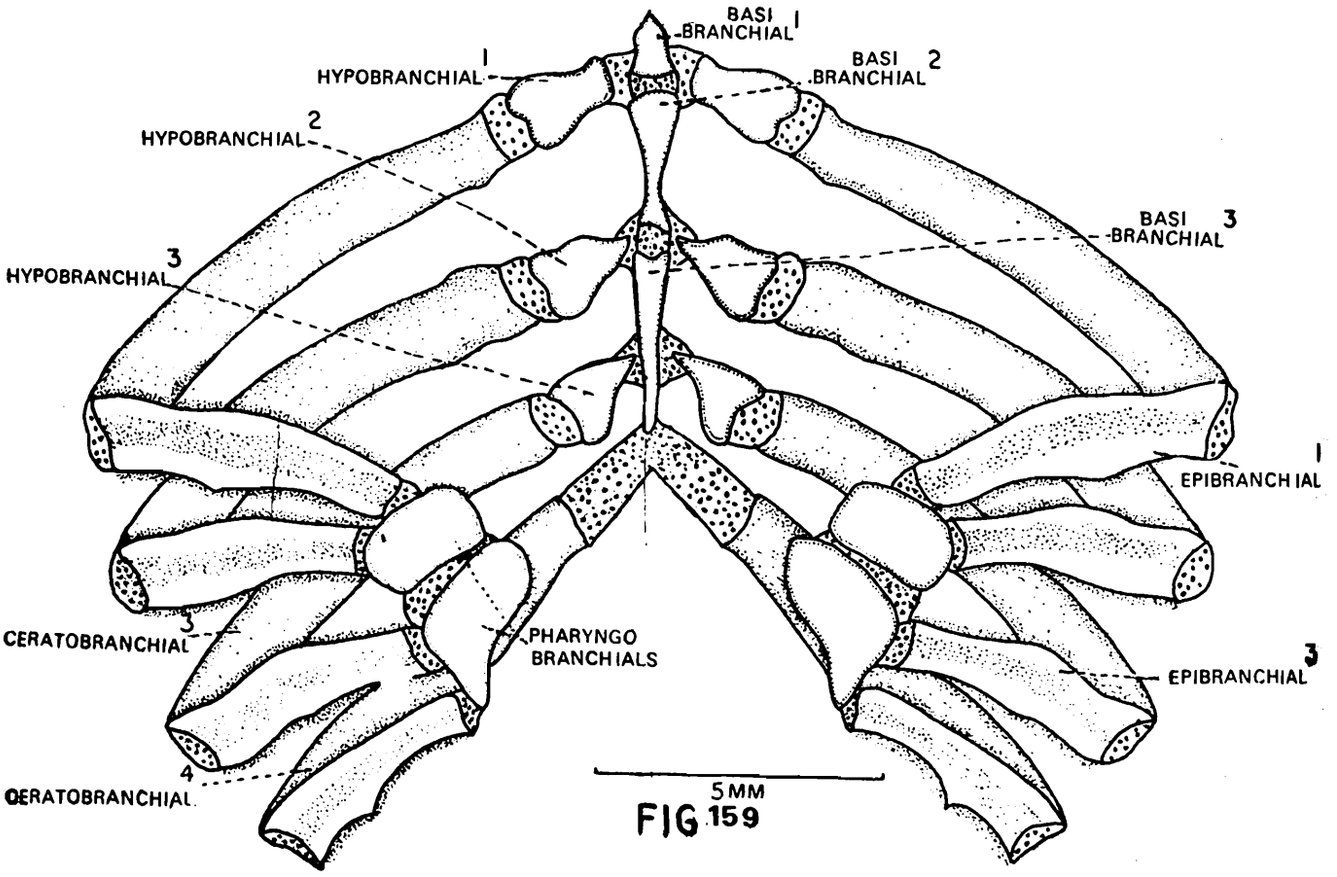


FIG 159

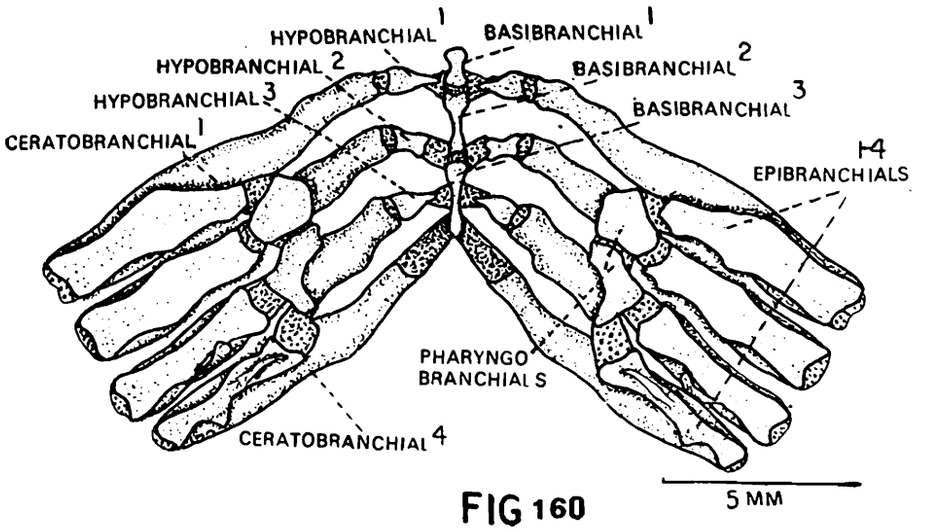


FIG 160

are tipped with cartilage. The first pair of hypobranchials shows differences in size and shape. Second hypobranchial articulates anteriorly with the posterior border of the second and anterior border of the third basibranchial. Posteriorly, it is attached to the second ceratobranchial. The third hypobranchial is connected anteriorly to the

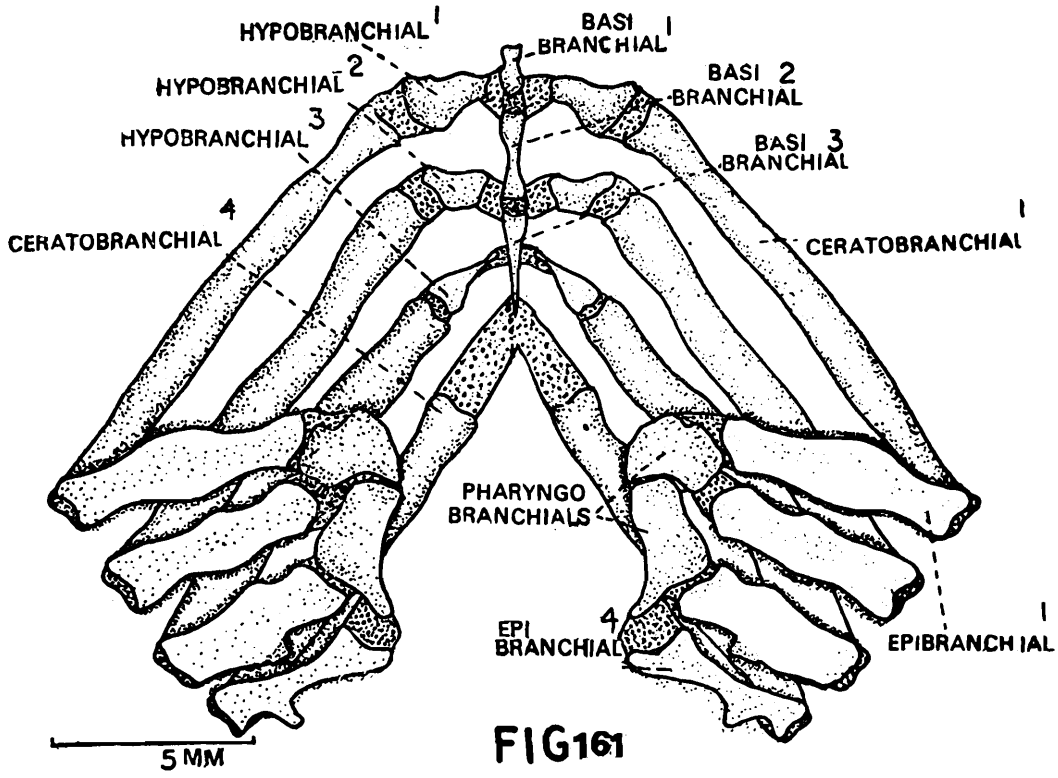


FIG161

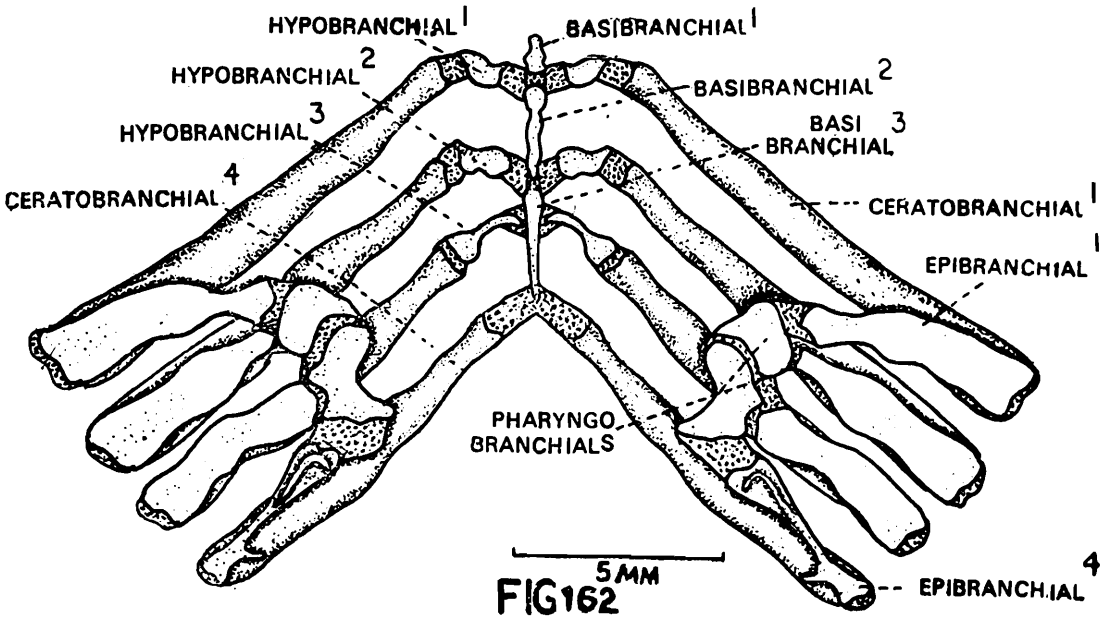


FIG162

posterior border of the third basibranchial and posteriorly, to the third ceratobranchial by a cartilaginous strip.

The first hypobranchial is longer than the second and the third ones in *Schizothorax richardsonii*, *Diptychus maculatus*, *Ptycobarbus*

conirostris, *Schizothoraichthys micropogon*, *Labeo dero*, *Schismatorhynchus nukta* and *Garra lamta*. In *Rasbora daniconius* and *Aspidoparia morar*, the second one is longer than the other two while the three hypobranchials are equal in size in *Schizopygopsis stoliczkae*. The shape of all the three hypohyals is different in the genera studied. The hypobranchials of the fourth and fifth branchial arches are absent and their ceratobranchials are connected directly to the base of third basibranchial by cartilaginous strips.

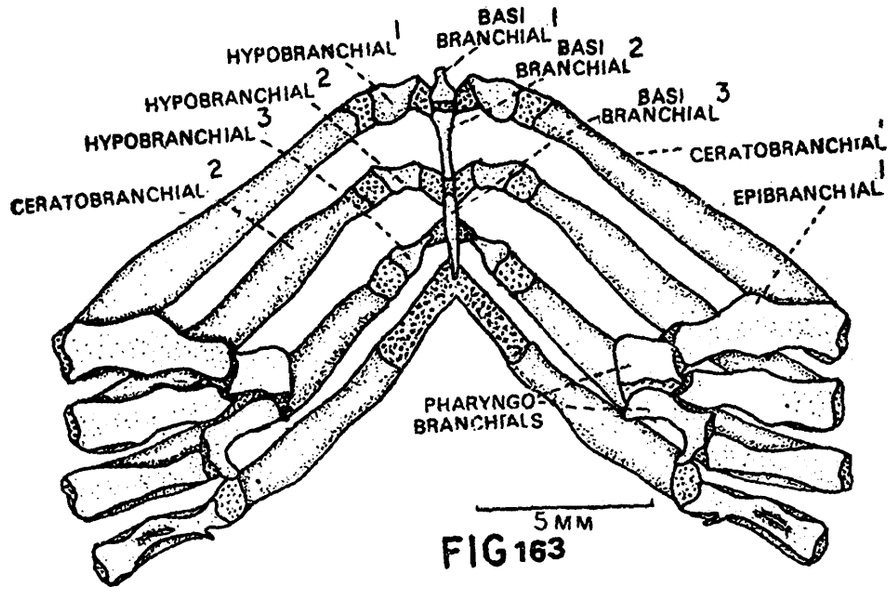


FIG 163

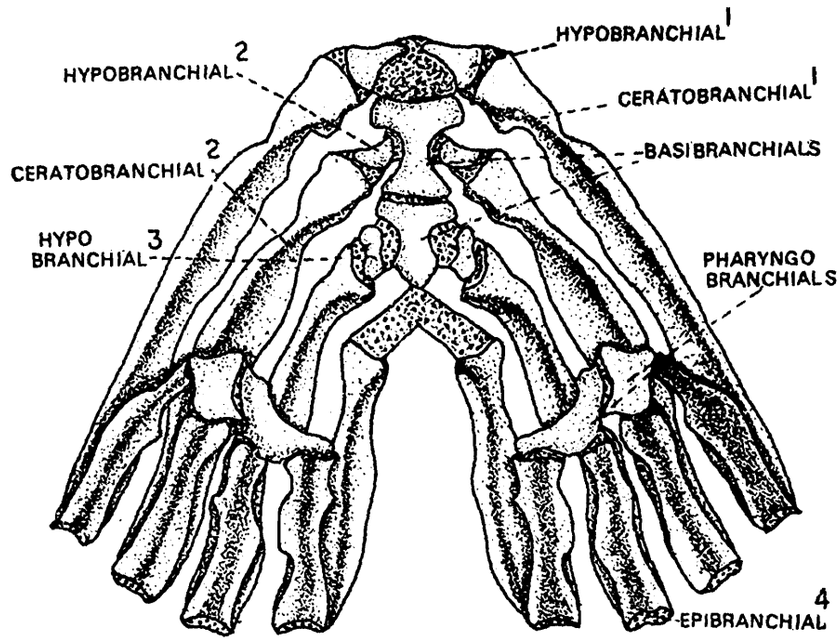


FIG 164

Basibranchials (Figs. 157-168) : They are small, median bones, placed along the ventromedian line between the hypobranchials of two sides and act as copulae for articulating with the branchial arches of two sides. There are uniformly three small, rod-shaped basibranschials in all the schizothoracine and rasborine genera studied. The first one is

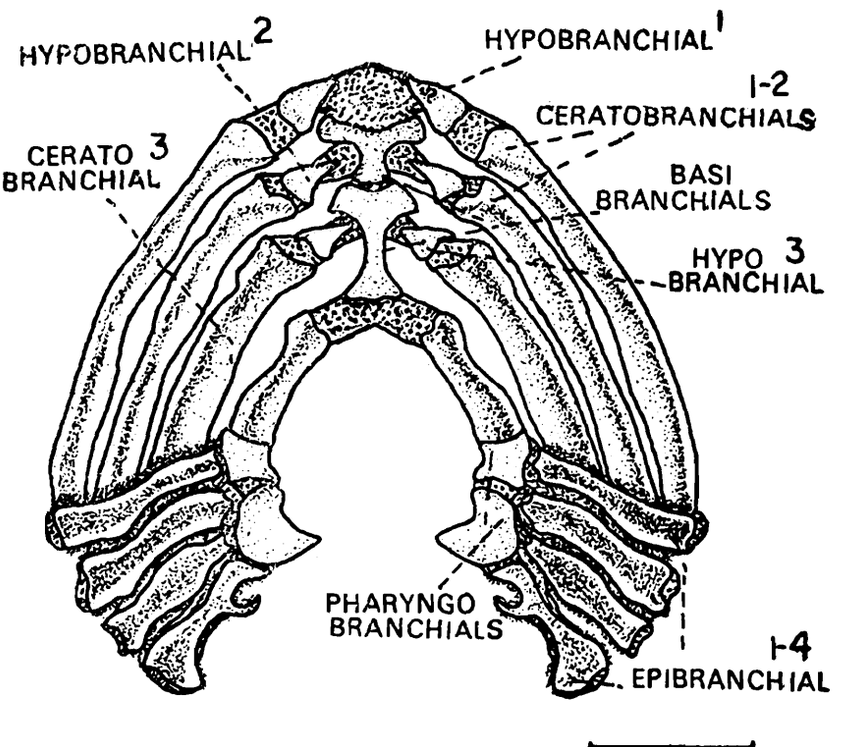


FIG 165

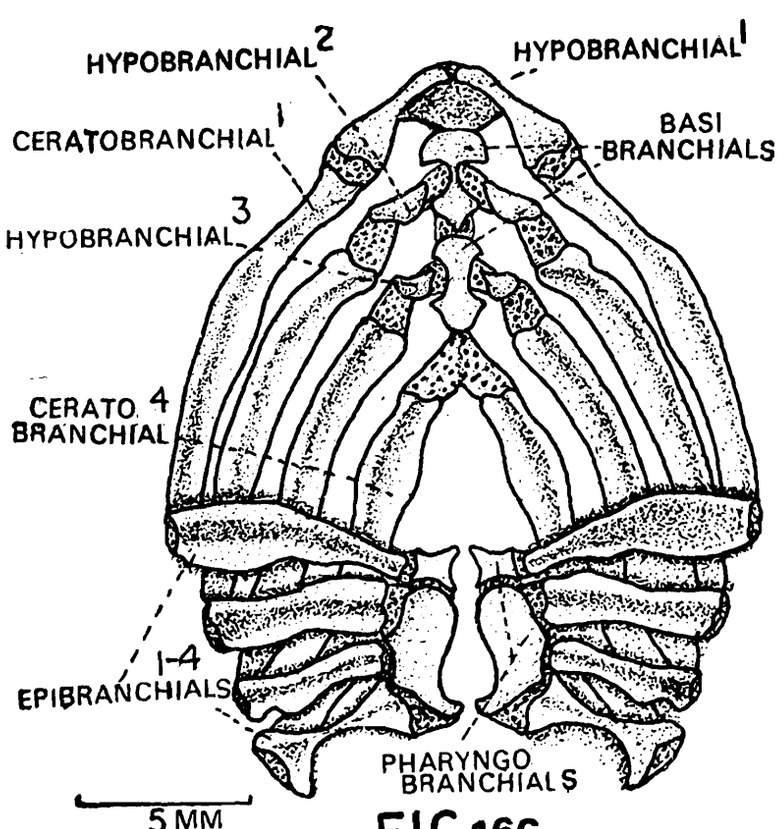


FIG 166

attached anteriorly by a cartilaginous piece to the posterior end of the basihyal and laterally, to the first pair of hypohyals. Second basibranchial, is attached anteriorly to the posterior end of first basibranchial, posteriorly, to the antetior end of third basibranchial and laterally, to the second pair of hypobranchials. The third basibranchial articulates anteriorly to the second basibranchial, laterally, to the third pair of hypobranchials and posteriorly, by a cartilaginous strip, to the fourth

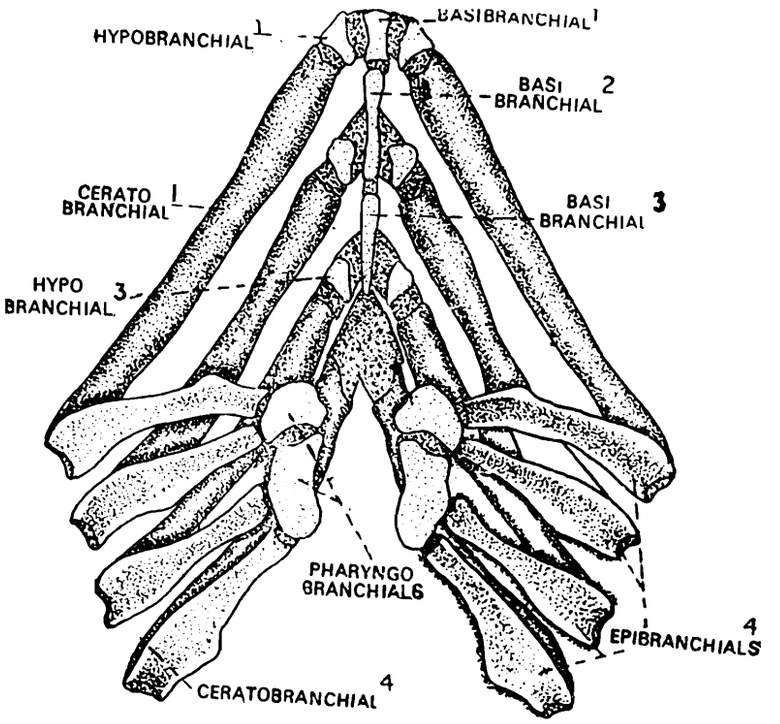


FIG 167

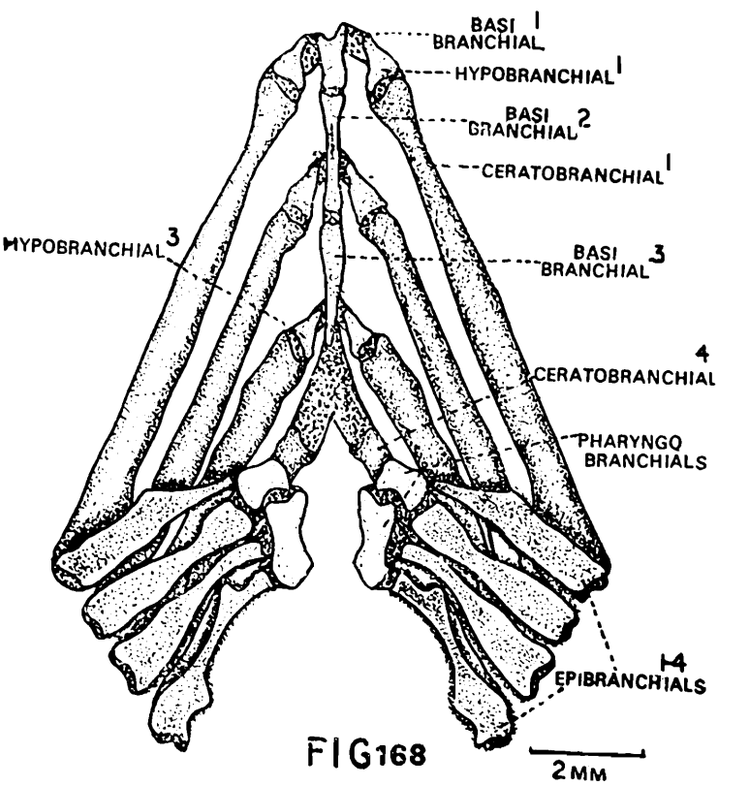
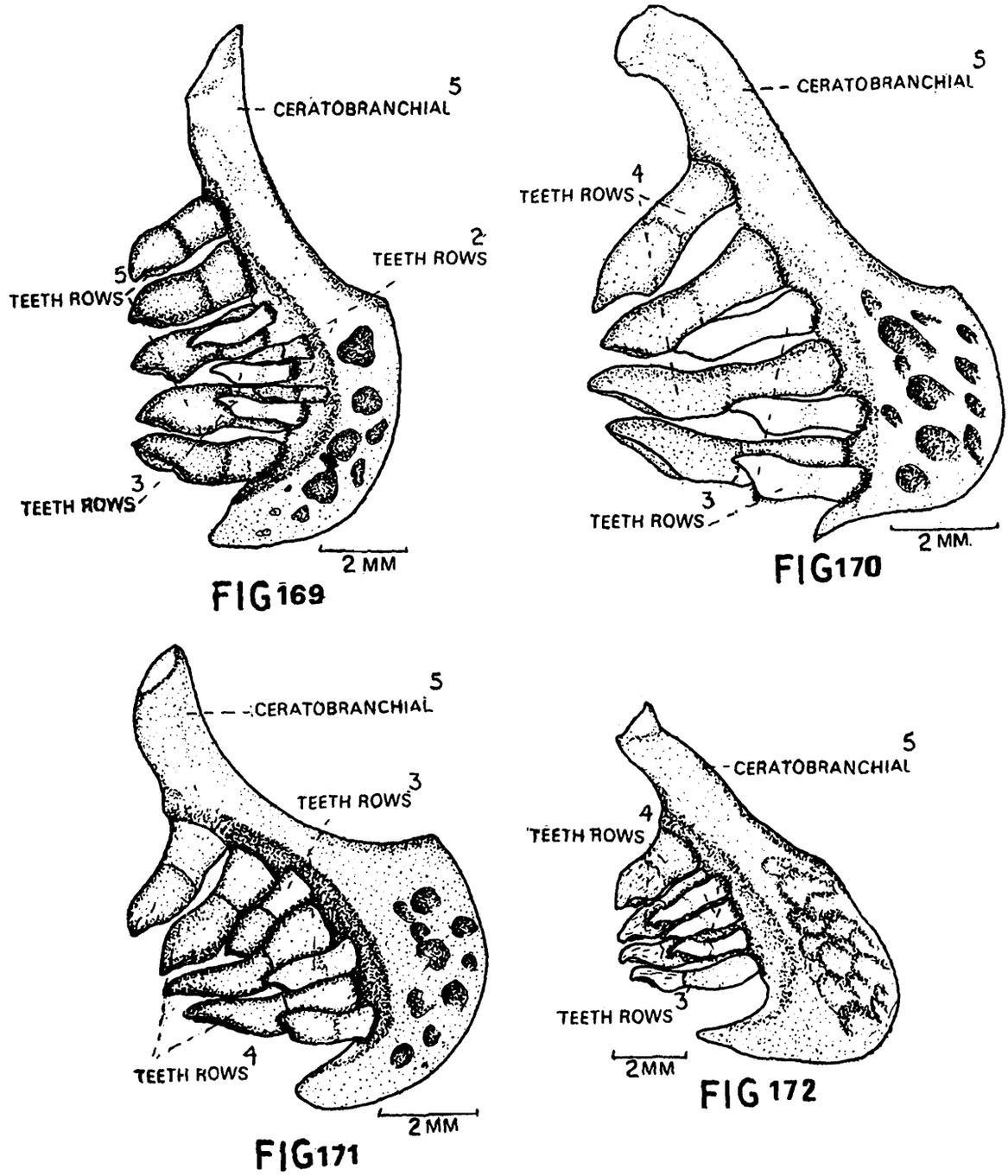


FIG168

ceratobranchials. In the cyprinine genera under report, only two umbrella-shaped basibranchials are observed. The base of the umbrella is broad in *Labeo dero* and *Schismatorhynchus nukta* while it is pointed in *Garra lamta*.

Fifth ceratobranchial (Figs. 169-180) : The fifth ceratobranchial of each side gets converted into a highly modified bone called the inferior pharyngeal bone. Each bone is a flattened concave, toothed bony plate



Figs. 169-180. Right inferior pharyngeal bones and teeth of *Schizothorax richardsonii*, *Diptychus maculatus*, *Schizopygopsis stoliczkae*, *Ptycobarbus conirostris*, *Schizothoraichthys micropogon*, *S. esocinus*, *S. labiatus*, *Labeo dero*, *Schismatorhynchus nukta*, *Garra lamta*, *Aspidoparia morar* and *Rasbora daniconius* respectively.

and is placed ventrolateral to the pharyngobranchial of its side. Its outer surface is highly fenestrated while the inner one bears strong teeth arranged in two to three rows. The two bones are connected to each other at their apices by connective tissue and to the third basibranchial by a long strip of connective tissue. The inferior pharyngeals also bear two rows of bony gill rakers. The pharyngeal dental formula and the number of rows in each genus studied shows considerable variation as listed in Table 1.

TABLE—1

PHARYNGEAL DENTAL FORMULA

Name of species	Dental formula	Number of rows
Schizothorax richardsonii (Gray)	5,3,2-2,3,5	3
Diptychus meculatus Steindachner	4,3-3,4	2
Schizopygopsis stoliczkae Steindachner	4,3-3,4	2
Ptycobarbus conirostris Steindachner	4,3-3,4	2
Schizothoraichthys micropogon (Heckel)	5,3,2-2,3,5	3
Schizothoraichthys esocinus (Heckel)	5,3,2-2,3,5	3
Schizothoraichthys labiatus (McClelland)	5,3,2-2,3,5	3
Labeo dero (Hamilton)	5,4,2-2,4,5	3
Schismatorhynchus nukta (Sykes)	5,4,2-2,4,5	3
Garra lamta (Hamilton)	5,4,2-2,4,5	3
Aspidoparia morar (Hamilton)	4,4,2-2,4,4	3
Rasbora daniconius (Hamilton)	5,4,2-2,4,5	3

The pharyngeal teeth are plough-shaped in *Labeo dero*, *Schismatorhynchus nukta*, *Aspidoparia morar* and *Schizothoraichthys micropogon* while in all the other genera reported, they are hooked and pointed. These teeth work against the horny pad, borne on the masticatory plate of the basioccipital.

(iii) *Opercular bones* ;

These are a set of paired dermal bones which have secondarily come to establish a contact with the osteocranium, particularly the branchiocranium, for discharging a common function i. e. the respiration. The opercular bones and the adjoining branchiostegal rays jointly form the gill cover and are attached to the elements of the hyoid arch. There are four pairs of opercular bones : the operculum, interoperculum, subopercular and preoperculum. Whole of this series is connected to hyomandibular through operculum by a ball and socket arrangement. The hinge of the operculum flap is formed at the point of union of the operculum with hyomandibular.

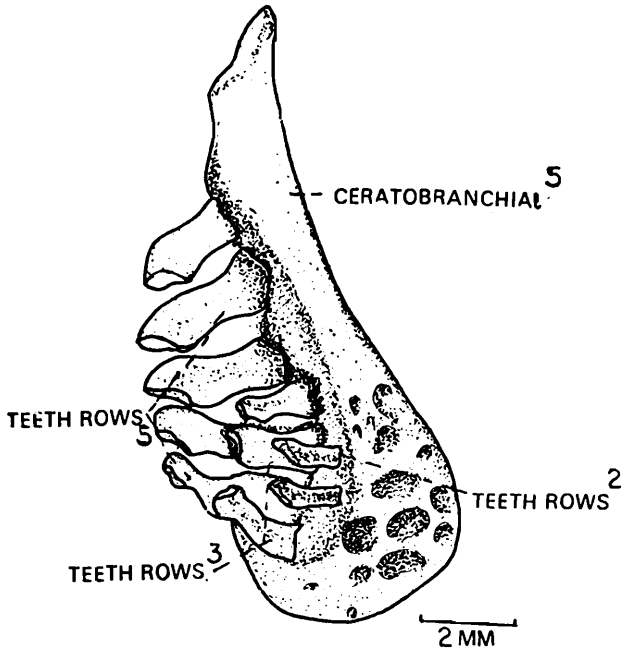


FIG 173

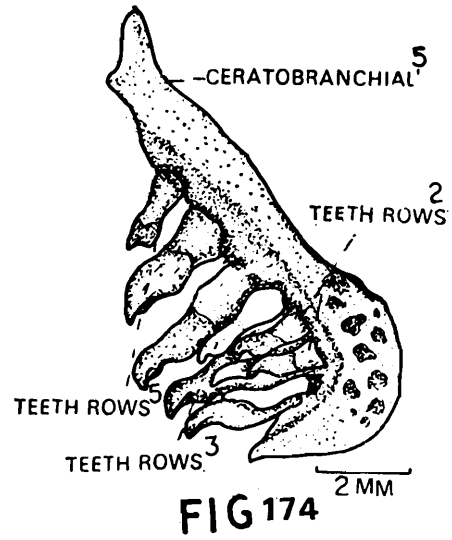


FIG 174

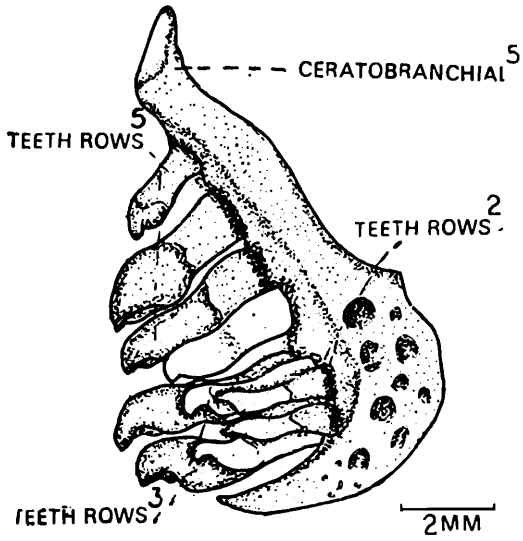


FIG 175

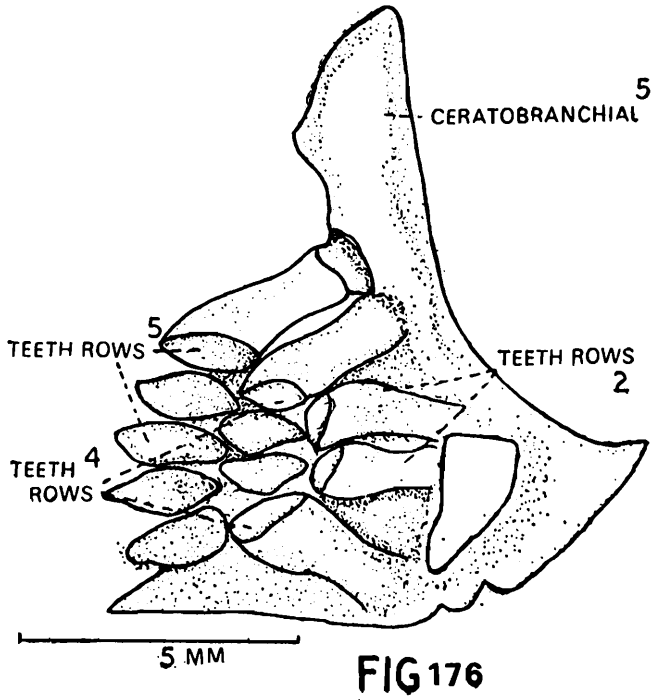


FIG 176

Operculum (Figs. 85-108) : Amongst these elements, the operculum is the largest, thin, shield-like bone which lies at the posterior border of gill cover. It is slightly concave internally and convex externally. Its anterior margin is almost vertical and plane, overlapped by the hind end of preoperculum. On the ventral side, there is a small notch into which interoperculum fits in. On the anterodorsal side, there is a small process, the opercular arm, which goes over the neck of hyomandibular. This projection is blunt and broad in *Diptychus maculatus*, *Ptycobarbus conirostris*, *Schizothoraichthys* spp., *Labeo dero*, *Garra lamta* and *Schismatorhynchus nukta*. It is elongated, thin and pointed in *Schizopygopsis stoliczkae* while it is pointed and small in *Schizothorax richardsonii*, *Rasbora daniconius* and *Aspidoparia morar*.

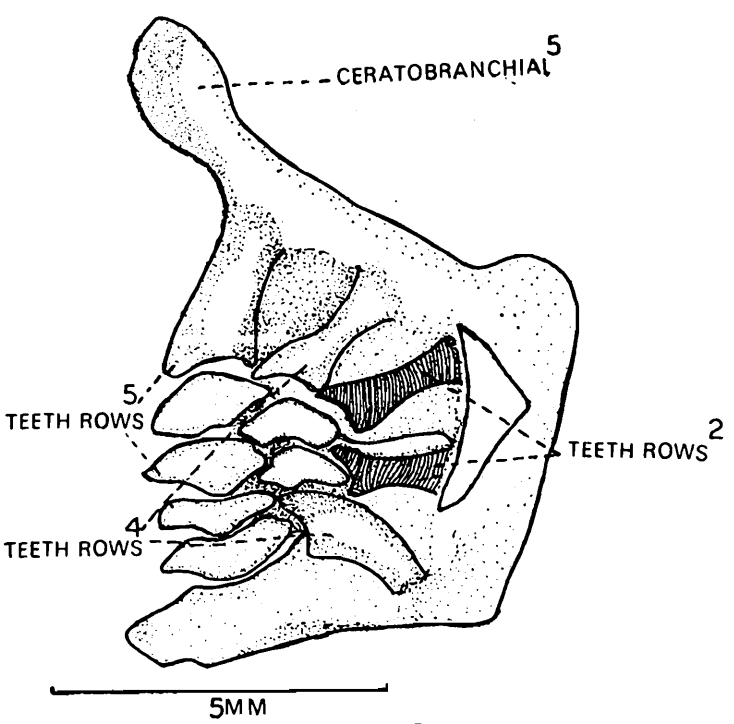


FIG 177

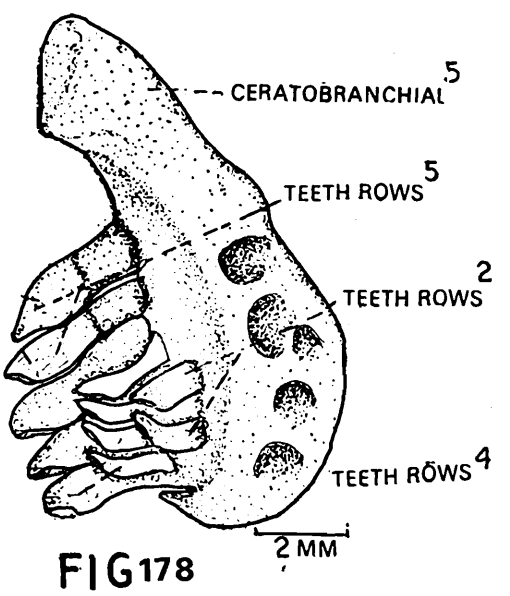


FIG 178

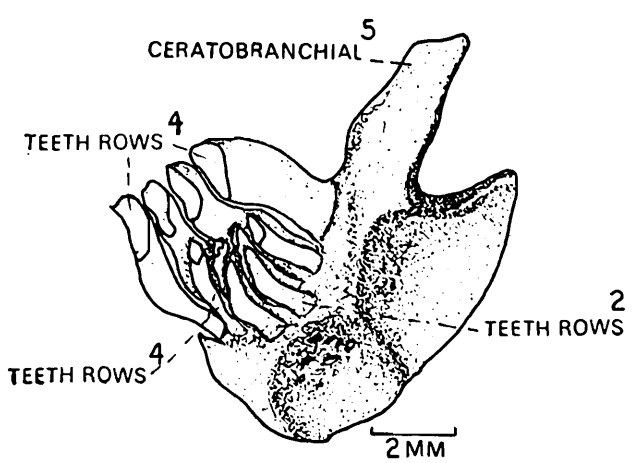


FIG 179

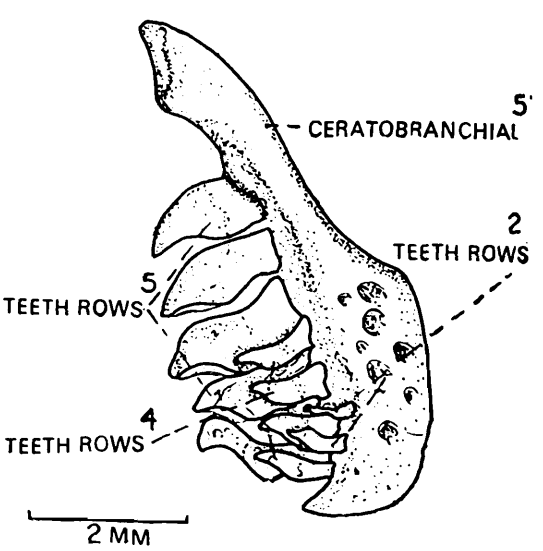


FIG 180

Interoperculum (Figs. 85-108) : It is a long and thin bone, broad at the posterior end and tapering towards the anterior end. It is situated just anterior to the ventroanterior corner of the operculum and suboperculum. Anteriorly, it is connected by a strong strip of ligament to posterior end of the mandible of its side. Its dorsal surface is concave and runs parallel to the preopercular limb. On its inner aspect, it overlaps the lateral margins of ceratohyals. In *Garra lamta*, the anterior

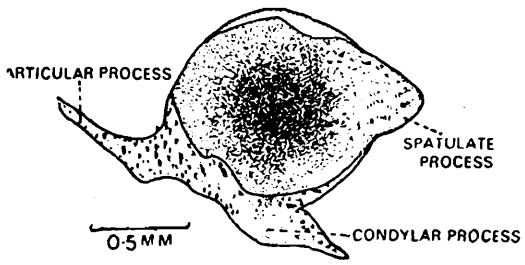


FIG 181

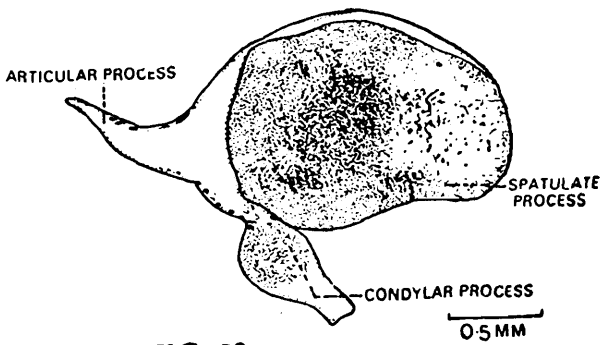


FIG 182

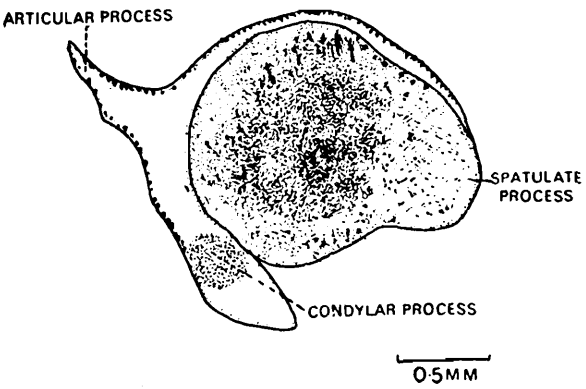


FIG 183

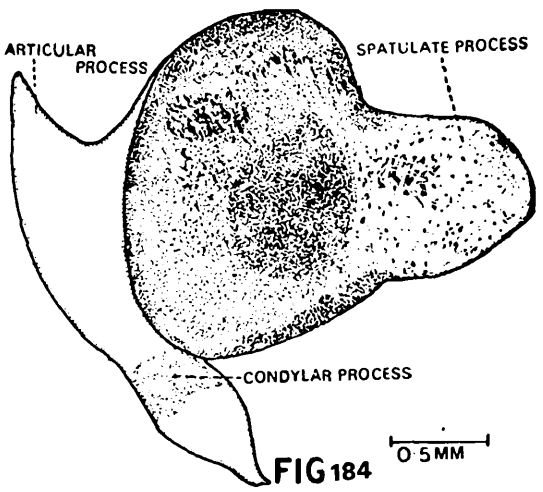


FIG 184

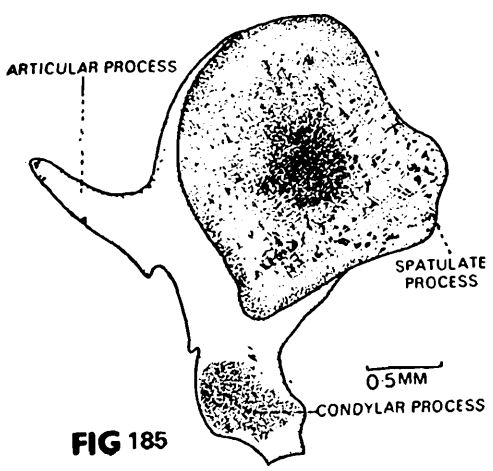


FIG 185

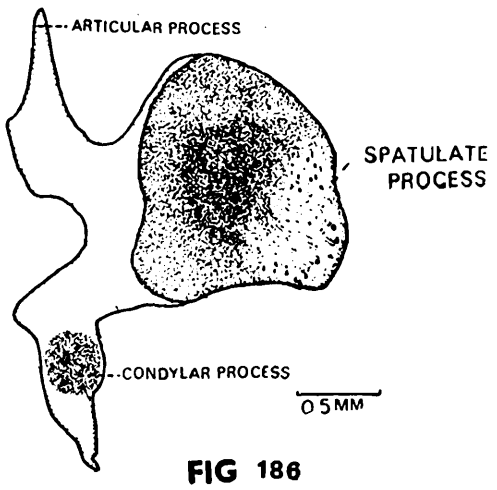


FIG 186

Figs. 181-192. Mesial views of the scaphium of *Schizothorax richardsonii, Diptychus maculatus, Schizopygopsis stoliczkae, Ptycobarbus conirostris, Schizothoraichthys. micropogon, S. esocinus S. labiatus, Labeo dero, Schismatorhynchus nukta, Garra lamta, Aspidoparia morar* and *Rasbora daniconius* respectively.

tip bears a small articular facet on its upper edge which articulates with the inner lower edge of the preoperculum. The upper edge of the interoperculum is pointed and blade-like.

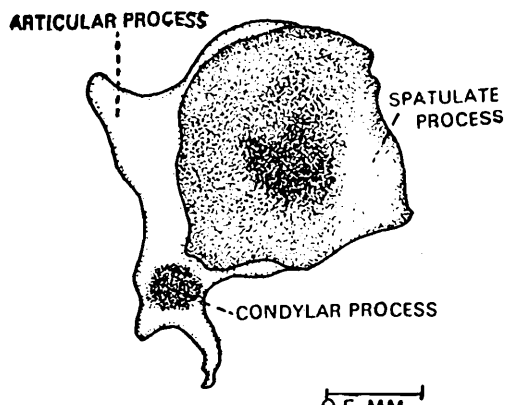


FIG 187

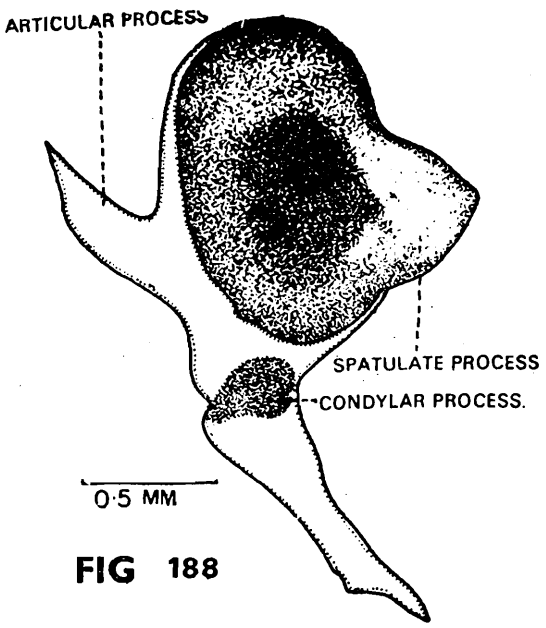


FIG 188

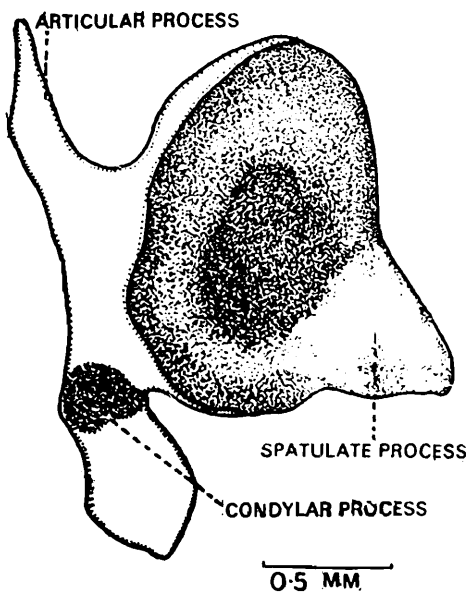


FIG 189

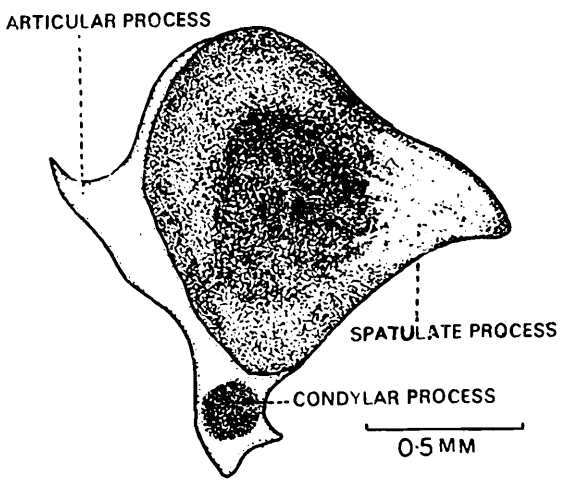


FIG 190

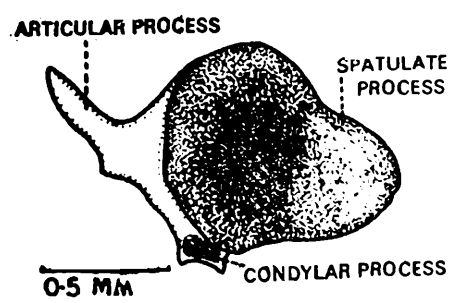


FIG 191

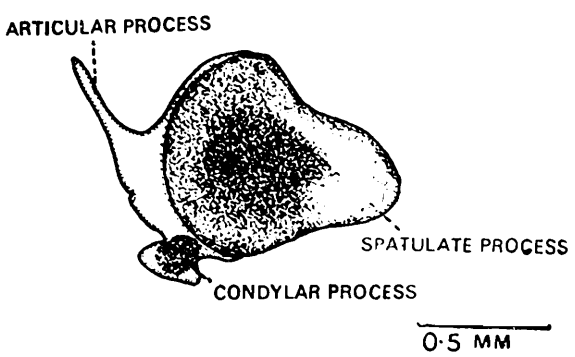


FIG 192

Suboperculum (Figs. 85-108) : On each side, it is a long bone, broad and truncated anteriorly and narrow posteriorly. It is overlain anteriorly by the interoperculum and dorsally by the lower edge of operculum. Its ventral border is free.

Preoperculum (Figs. 85-108) : It is semilunar in shape and lies over the lower posterior half of the hyomandibular. Its anterior ventral border articulates with the symplectic and quadrate and the anterior tip is connected by strong ligament to posterior end of mandible. On its inner aspect lies the interhyal. It encloses the preopercular portion of the mandibular lateral line sensory canal. The latter is irregularly perforated.

Branchiostegal rays (Figs. 133-144) : There is a uniform set of three branchiostegal rays in all the genera under report. They are flattened, laterally compressed dermal bones whose bases are attached to the cerato and epi-hyals. They strengthen the gill membranes and help in respiratory process.

B. WEBERIAN APPARATUS

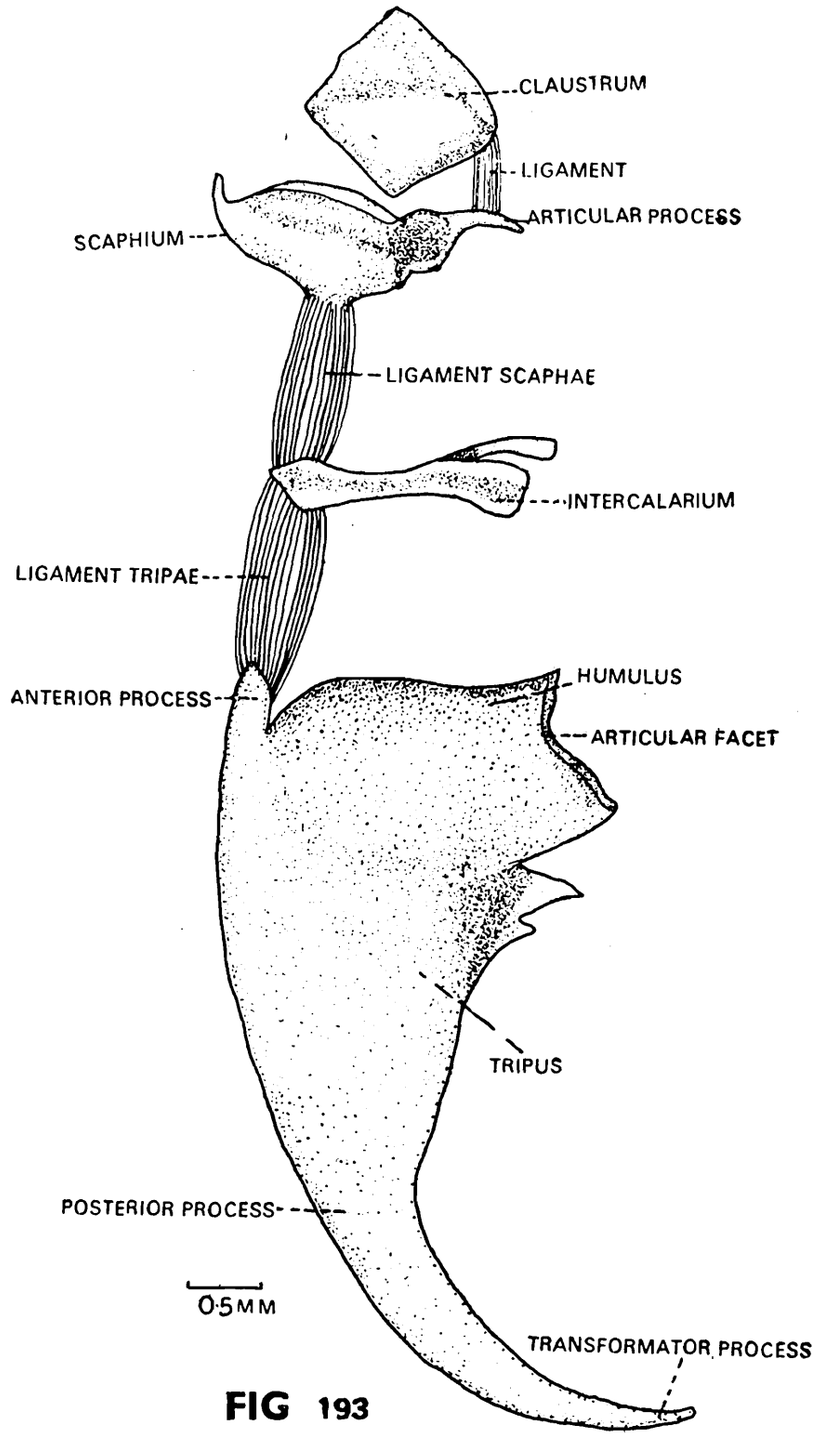
The configuration of the Weberian apparatus of cyprinids is peculiar to this group of fishes and differs from other Ostariophysi. It comprises the pars auditum and pars sustentaculum.

Pars Auditum

This region includes a chain of small bones on either side of anterior four vertebrae. Each chain consists of four small bony elements, viz. the claustrum, the scaphium the intercalarium and the tripus, aligned in an antero-posterior manner so as to establish a connection with the swim bladder and the membranous labyrinth.

Claustrum (Figs. 193-204) : It is the anterior most element of the Weberian chain which has the shape of an inverted bell. It lies dorsal to the scaphium and fits against the spatulate process of scaphium in such a manner that the association of the two resembles a brachiopod shell. It is embedded into a strip of ligament which guards the opening of cavum sinus imparis and strengthens the wall of neural canal. There is an ascending process which projects away from the body and articulates to the second neural arch. The ascending process is rudimentary in *Schizothorax richardsonii* and *Garra lamta*. In *Schizothoraichthys micropogon*, it is developed, though to a less degree, while it is much developed in rest of the genera.

Scaphium (Figs. 181-204) : It is a small cup-like ossicle resembling an earthen lamp. It consists of three parts : (i) a cup-shaped main body-the spatulate process. (ii) a rounded condylar process which is attached to the centrum of first vertebra through a small cartilaginous or bony rod. (iii) a rod-like, sharp articular process which ariculates with the first neural arch.



Figs. 193-204. Ventral aspects of the chain of Weberian ossicles of *Schizothorax richardsonii, Diptychus maculatus, Schizopygopsis stoliczkae, Ptycobarbus conirostris, Schizothoraichthys micropogon, S. esocinus. S. labiatus, Labeo dero, Schismatorhynchus nukta, Garra lamta, Aspidoparia morar* and *Rasbora daniconius* respectively.

The spatulate process is scooped inside and is convex on the outer side. This convex face abuts against the concave face of the claustrum and is in contact with the opening of cavum sinus imparis. The condylar process is attached to the centrum of first vertebra. The

vertical process, connecting the condylar process with the first neural arch is very well developed in schizothoracine genera, *Labeo dero* and *Schismatorhynchus nukta* but it is very much reduced in other genera

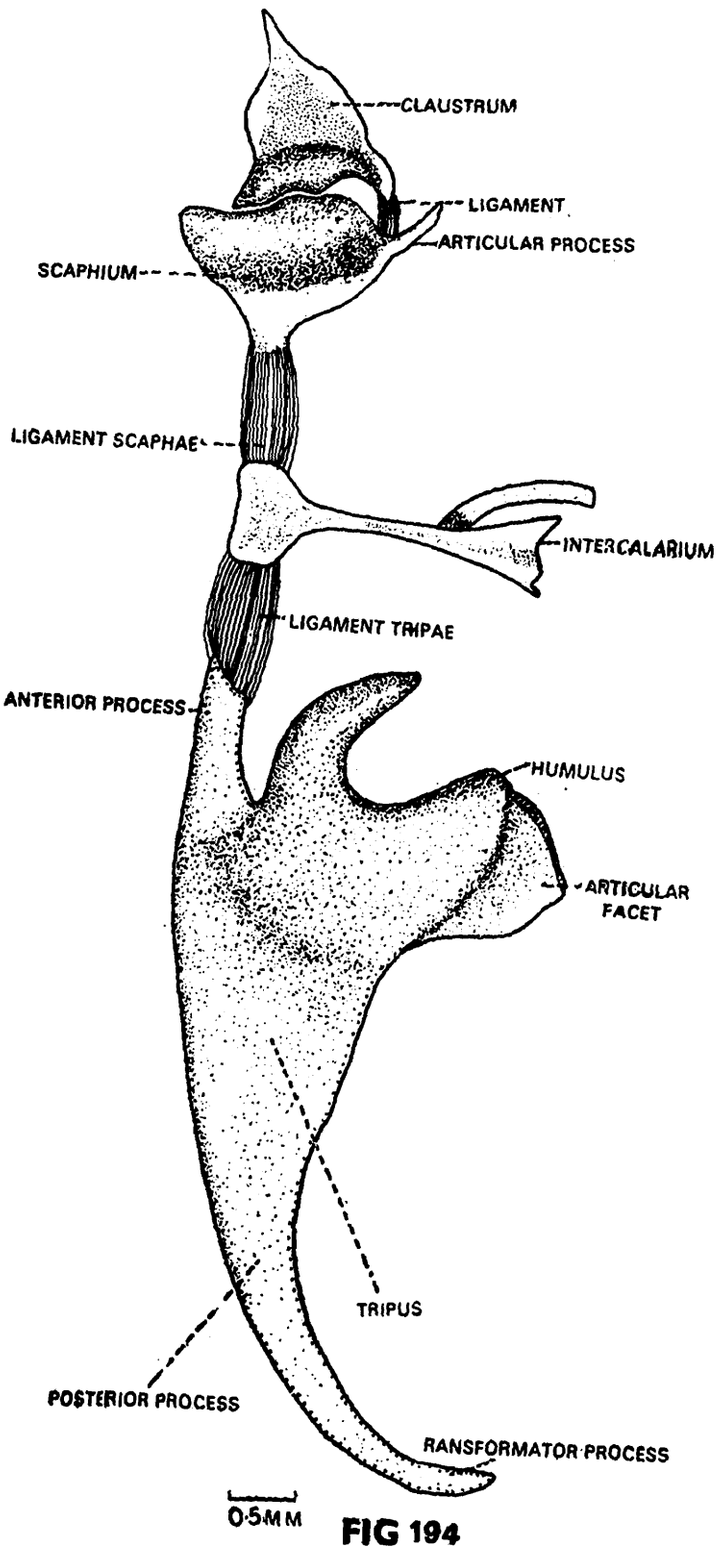


FIG 194

reported. The articular process of scaphium is sharp and long in all the species studied except in *Garra lamta* and *Schizothoraichthys labiatus*. In the former, it is very much short and sharp while it is small and

blunt in the latter species. On its posterior face, a ligament-the ligament scaphae-connects this bone with intercalarium.

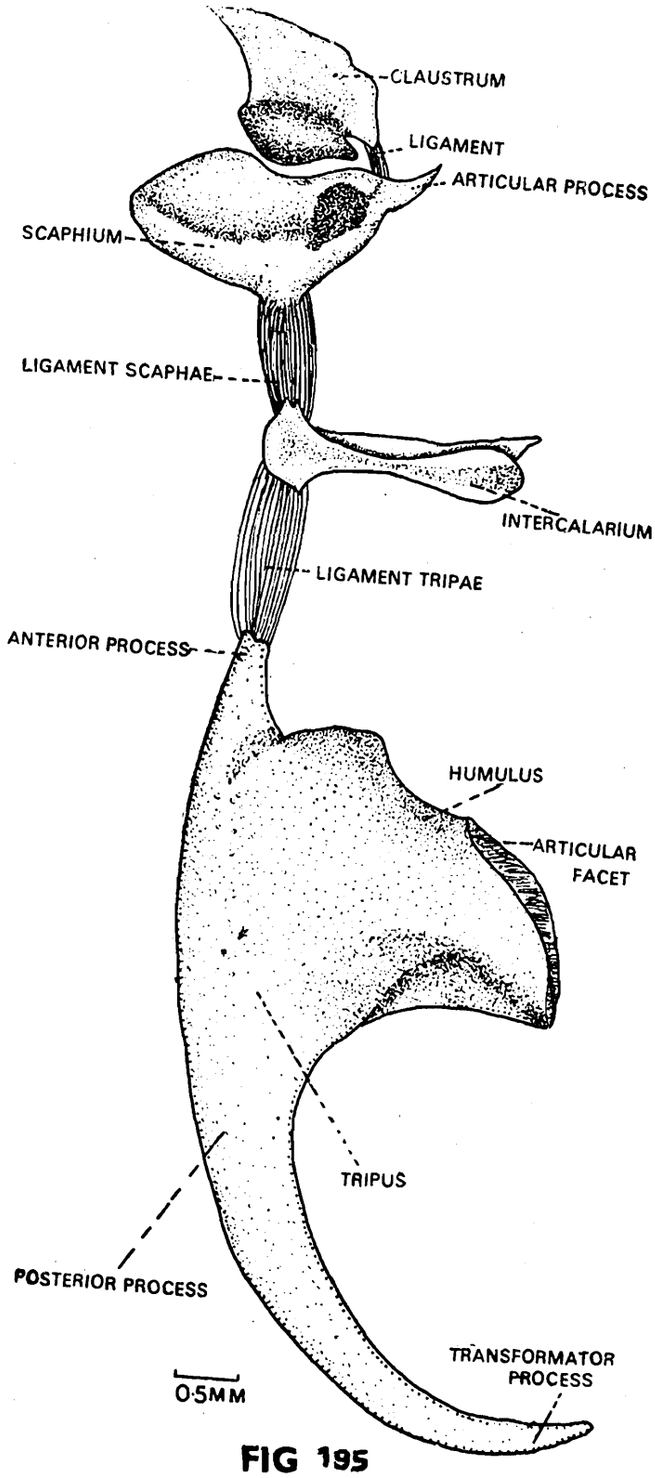


FIG 195

Intercalarium (Figs. 193-204) : It is attached anteriorly to the scaphium through ligament scaphae and posteriorly to the anterior process of the tripus through ligament tripae. It articulates with the anterior face of fused second and third neural arches through an arti-

cular process. The tip of the latter is bifid. There is no variation in this ossicle except that in *Garra lamta*, its size is reduced.

Tripus (Figs. 193-204) : The tripus is the largest and most promi-

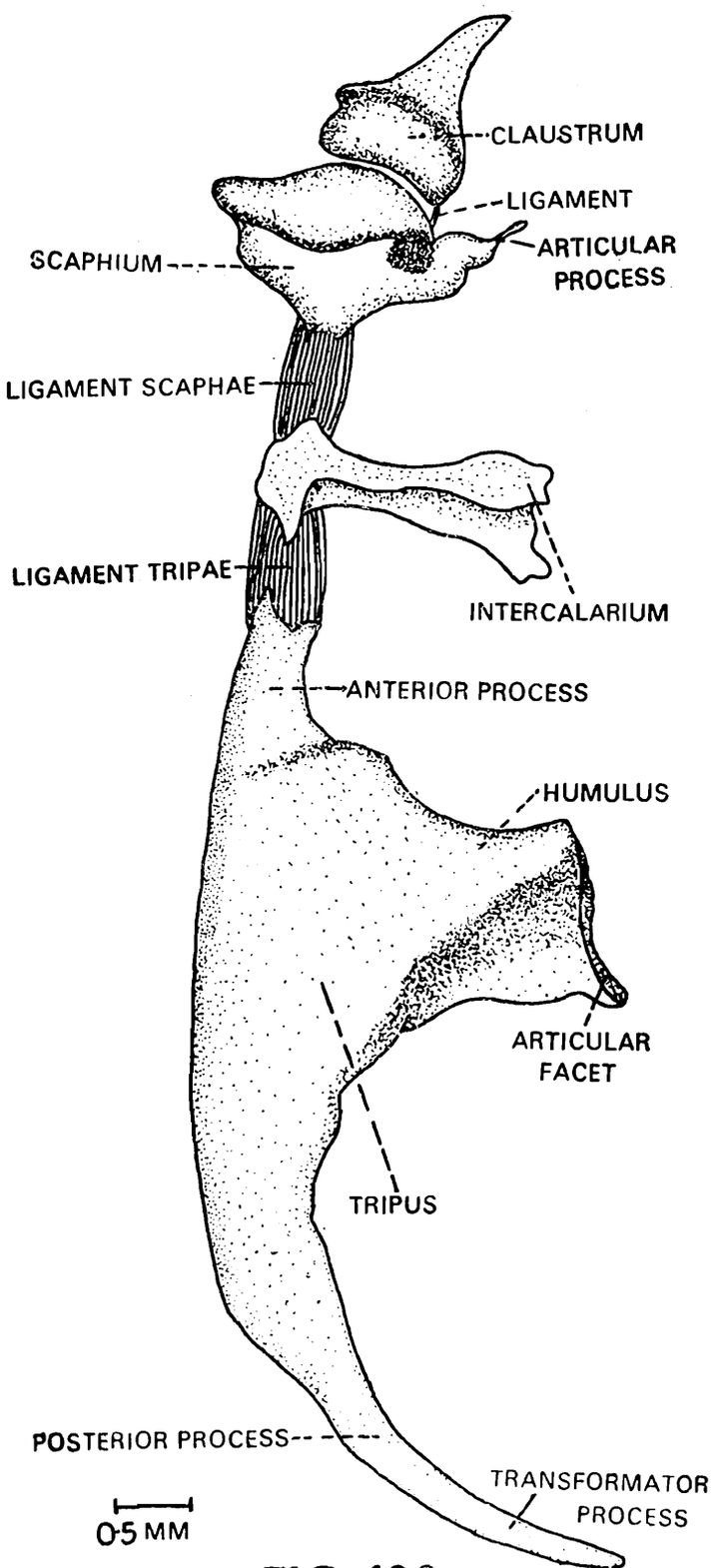


FIG 196

nent ossicle of the chain. It is divided into an anterior process, the articular process, and the transformator process. The length of the anterior process is small in *Schizothorax richardsonii*, *Schizothoraichthys*

spp., *Rasbora daniconius* and *Aspidoparia morar* while it is long in *Diptychus maculatus*, *Labeo dero*, *Schismatorhynchus nukta* and *Garra lamta*. It is inbetween the two categories in *Ptycobarbus conirostris*.

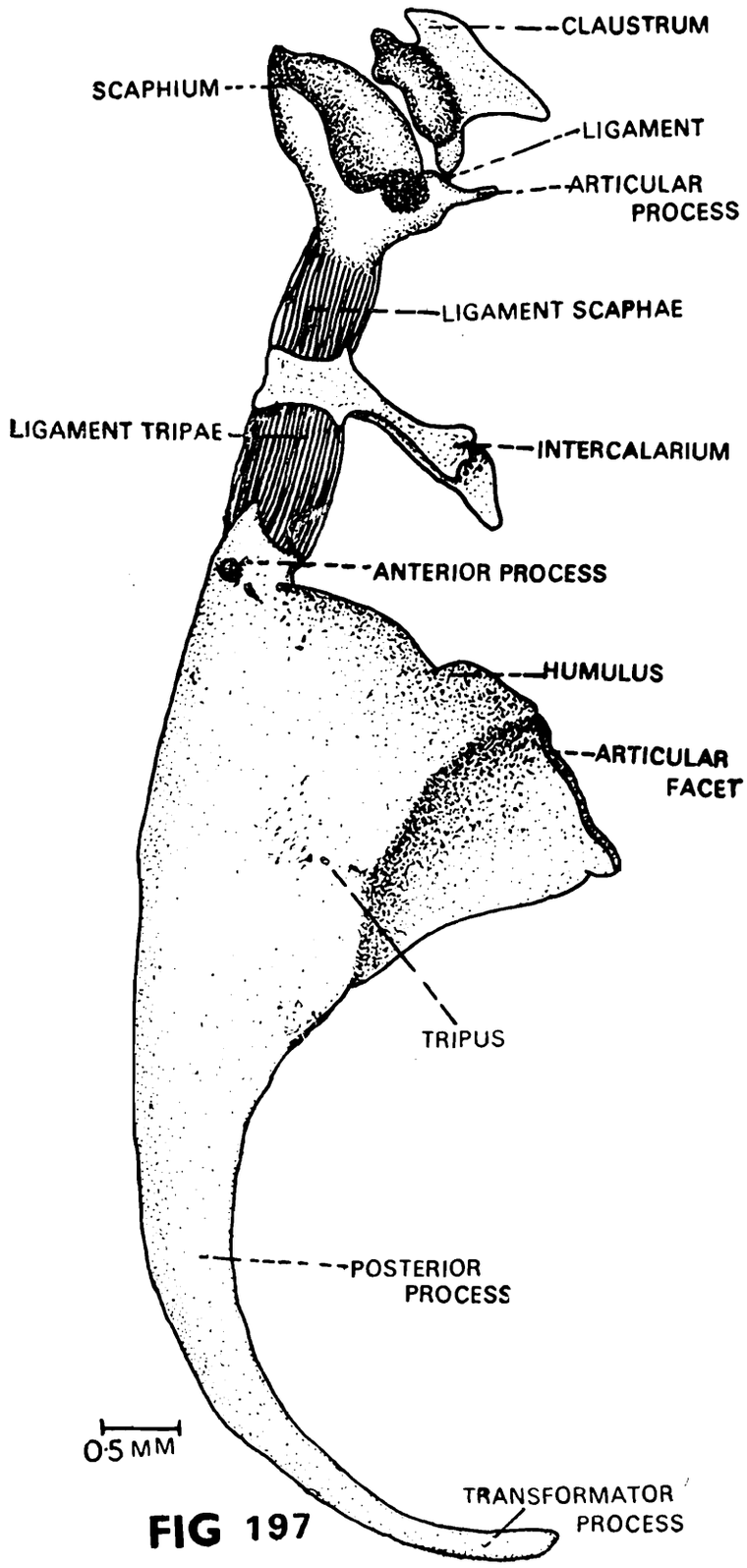


FIG 197

The articular process is the broadest part of the tripus and is aligned in a vertical fashion. It is attached to the lateral side of the complex vertebra. In *Diptychus maculatus*, a prominently strong hooked process

arises from the ventral side of base of the articular process. In *Schizopygopsis stoliczkae*, this process is rudimentary while it is absent in rest of the species. The transformator process is thin curved and is the

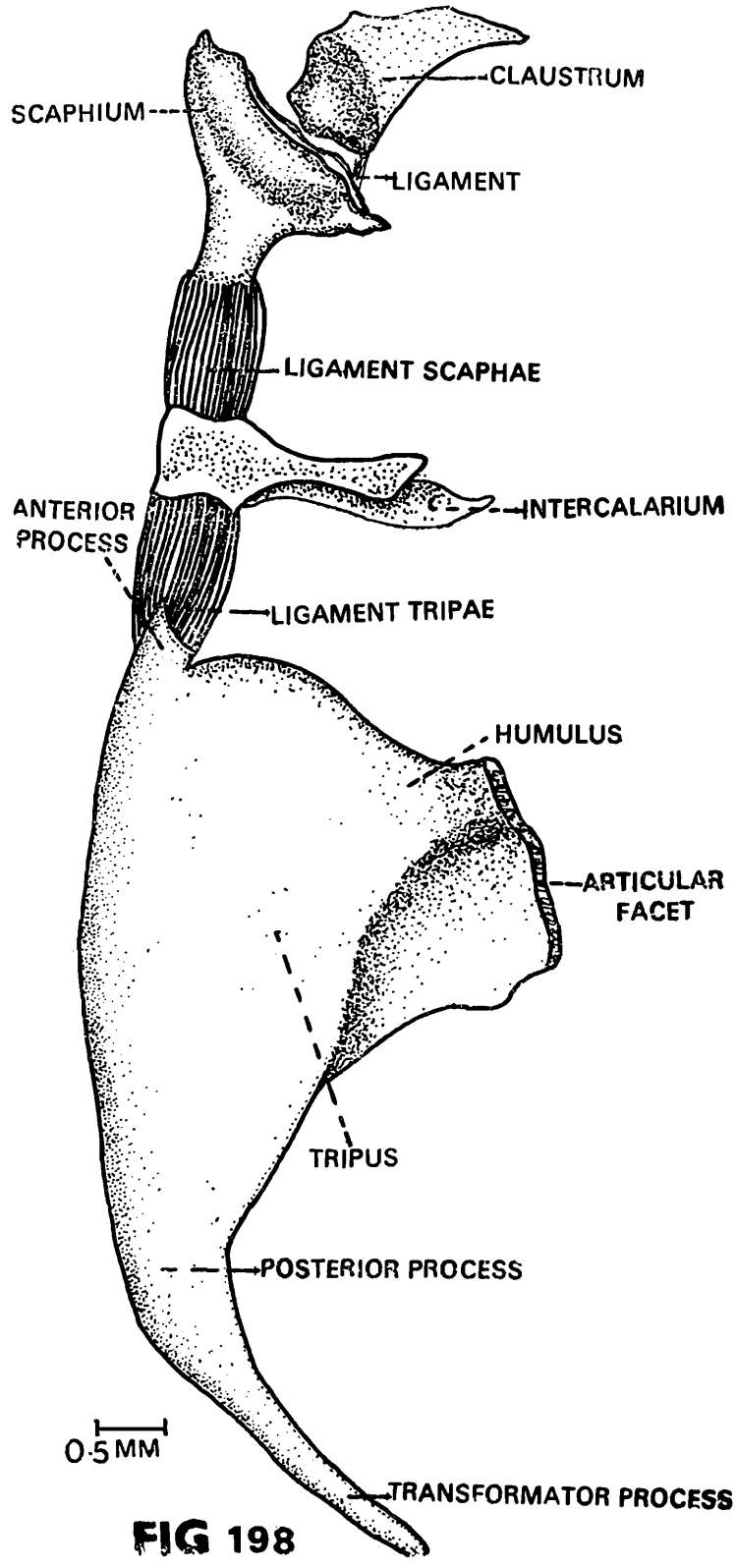


FIG 198

posterior most part of the tripus. It passes along the ventral side of the base of fourth parapophysis and runs behind the suspensorium. The transformator process is small in *Garra lamta* as compared to

other genera studied. In *Aspidoparia morar*, the body of tripus bears an elongated depresion on the ventral side. Such a depression is also present in *Schismatorhynchus* and *Rasbora daniconius* which is shallower.

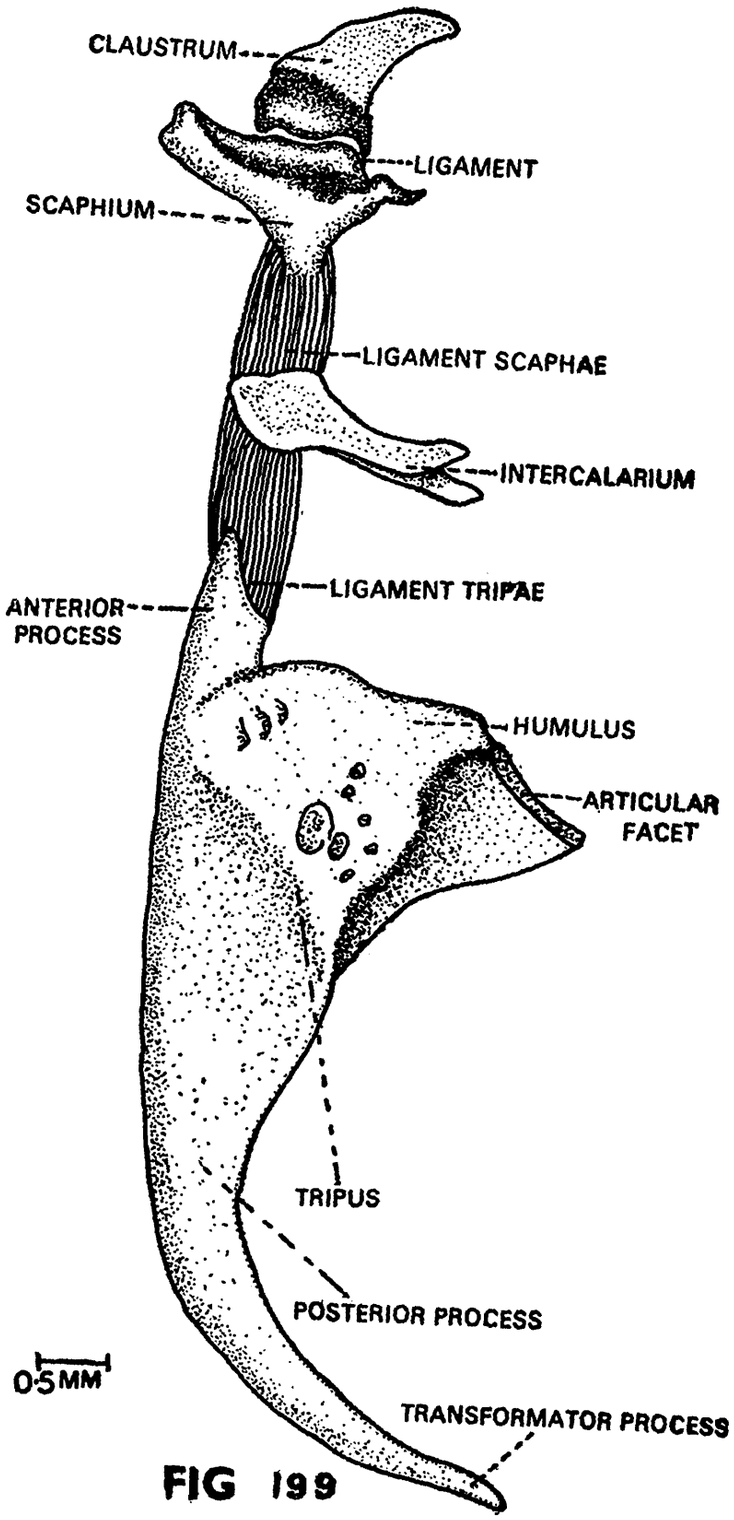


FIG 199

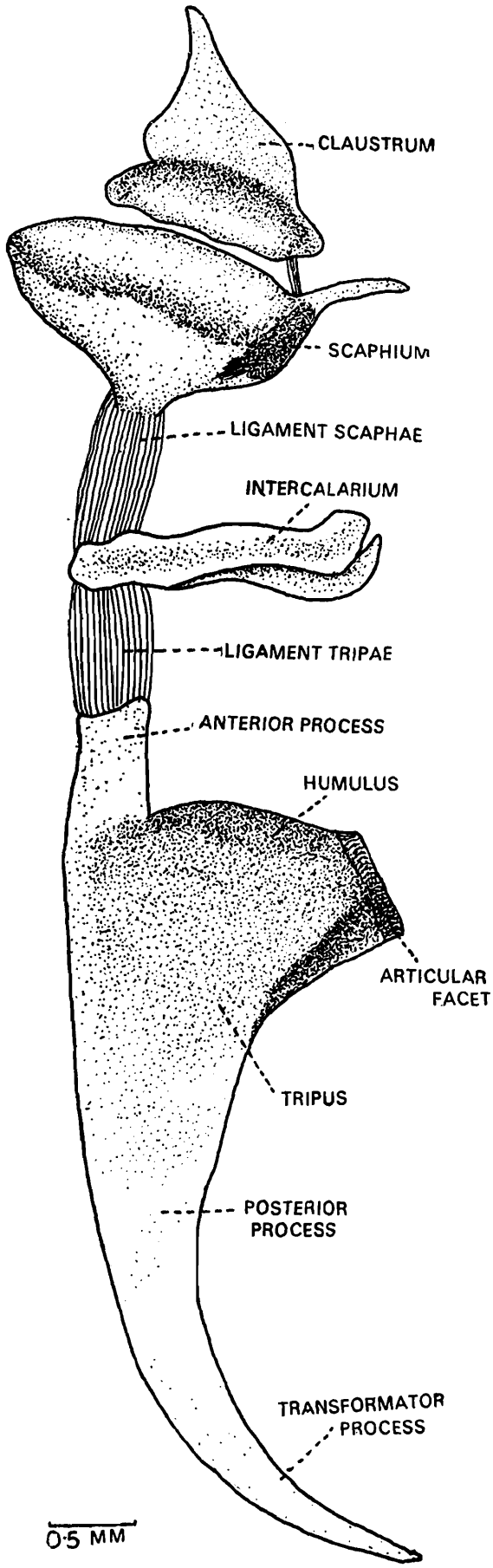

CLAUSTRUM
SCAPHIUM
LIGAMENT SCAPHAE
INTERCALARIUM
LIGAMENT TRIPAE
ANTERIOR PROCESS
HUMULUS
ARTICULAR FACET
TRIPUS
POSTERIOR PROCESS
TRANSFORMATOR PROCESS
0·5 MM

FIG 200

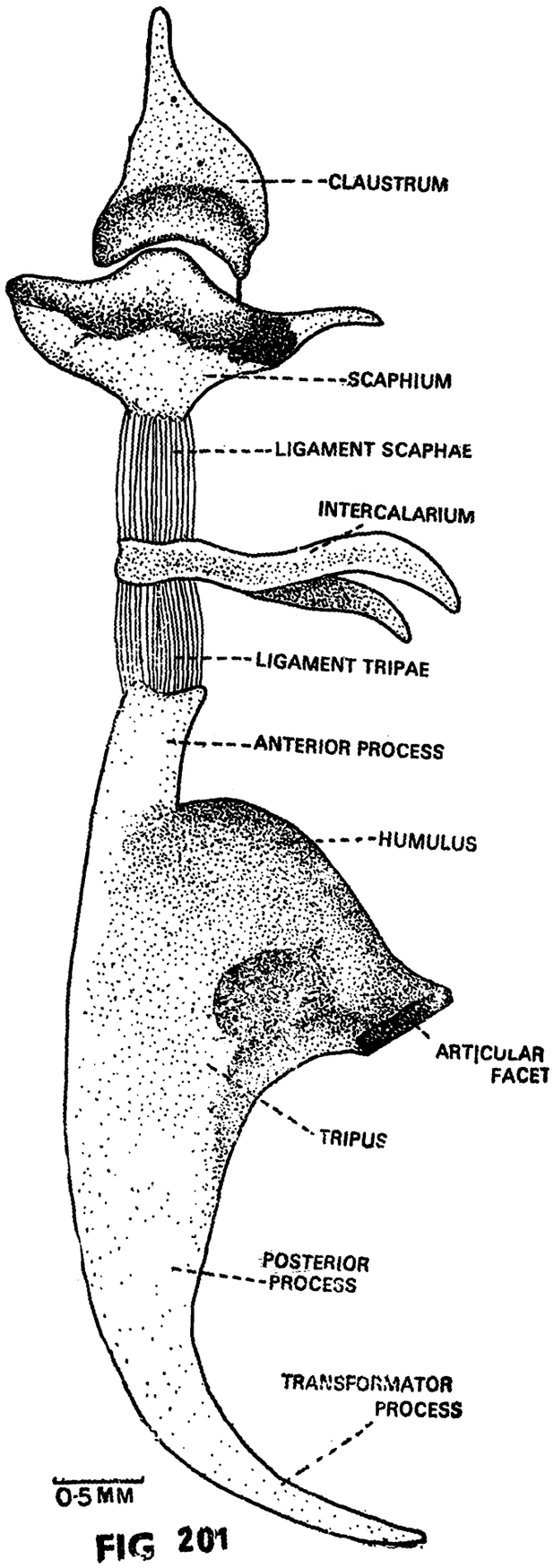

CLAUSTRUM
SCAPHIUM
LIGAMENT SCAPHAE
INTERCALARIUM
LIGAMENT TRIPAE
ANTERIOR PROCESS
HUMULUS
ARTICULAR FACET
TRIPUS
POSTERIOR PROCESS
TRANSFORMATOR PROCESS
0·5 MM

FIG 201

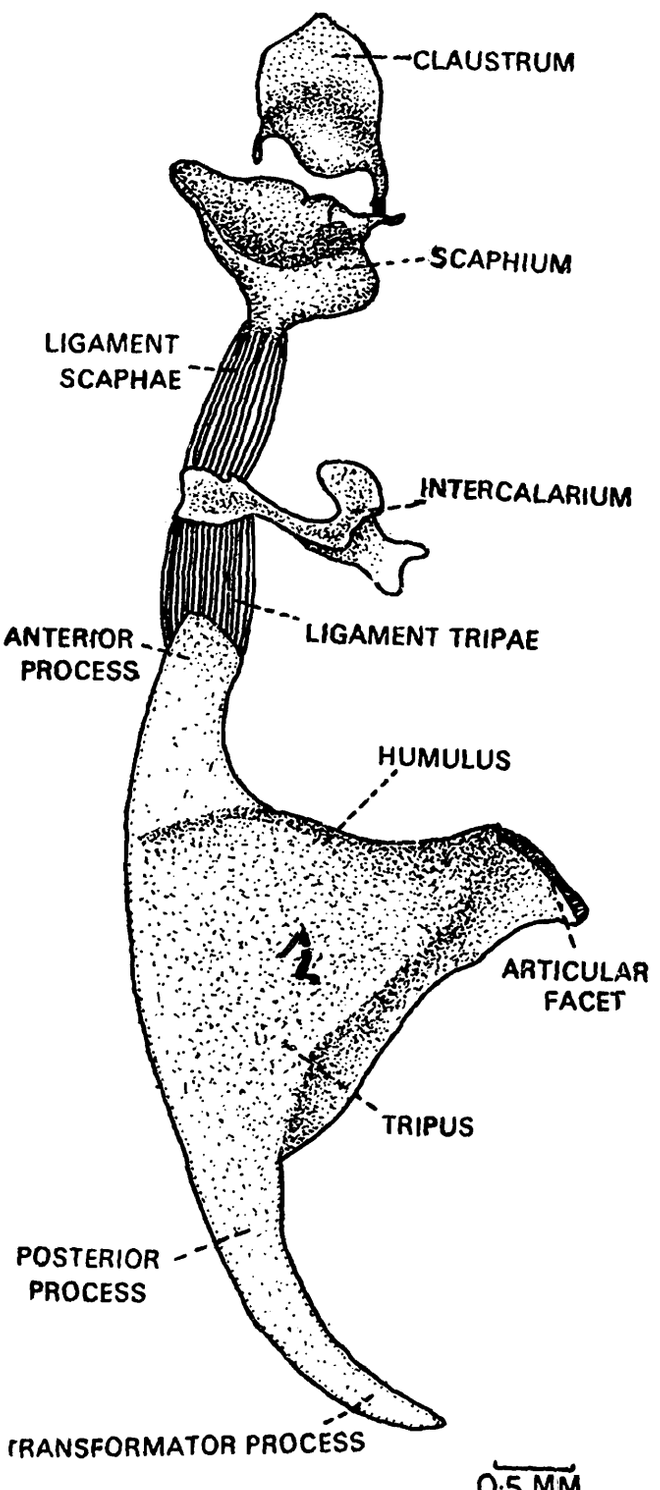

CLAUSTRUM
SCAPHIUM
LIGAMENT SCAPHAE
INTERCALARIUM
LIGAMENT TRIPAE
ANTERIOR PROCESS
HUMULUS
ARTICULAR FACET
TRIPUS
POSTERIOR PROCESS
TRANSFORMATOR PROCESS
0·5 MM

FIG 202

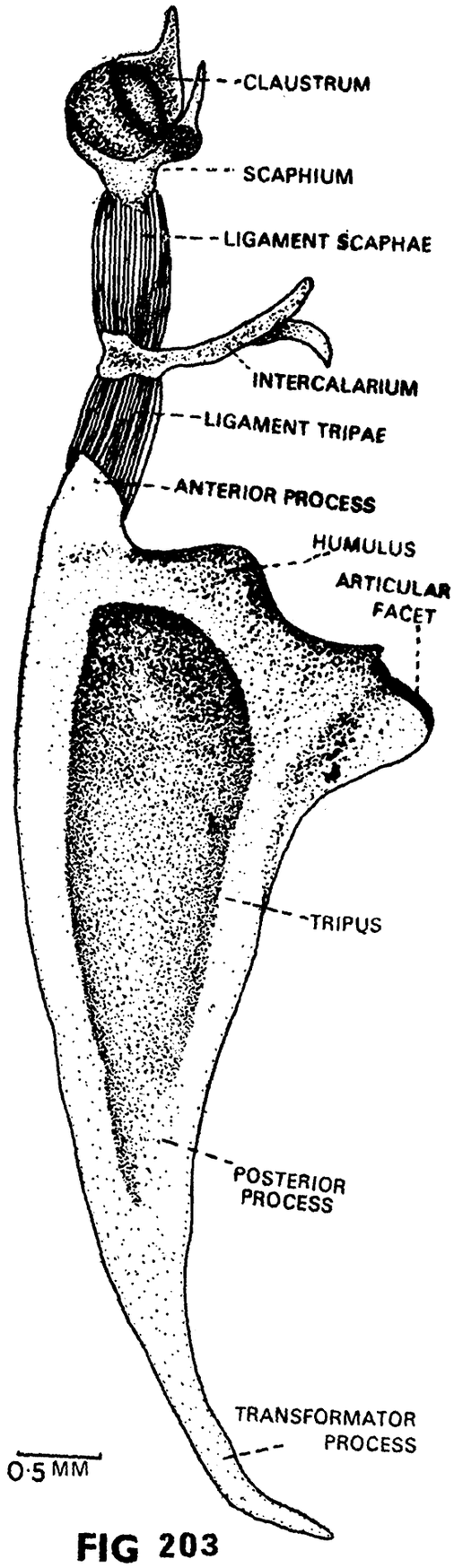

CLAUSTRUM
SCAPHIUM
LIGAMENT SCAPHAE
INTERCALARIUM
LIGAMENT TRIPAE
ANTERIOR PROCESS
HUMULUS
ARTICULAR FACET
TRIPUS
POSTERIOR PROCESS
TRANSFORMATOR PROCESS
0·5 MM

FIG 203

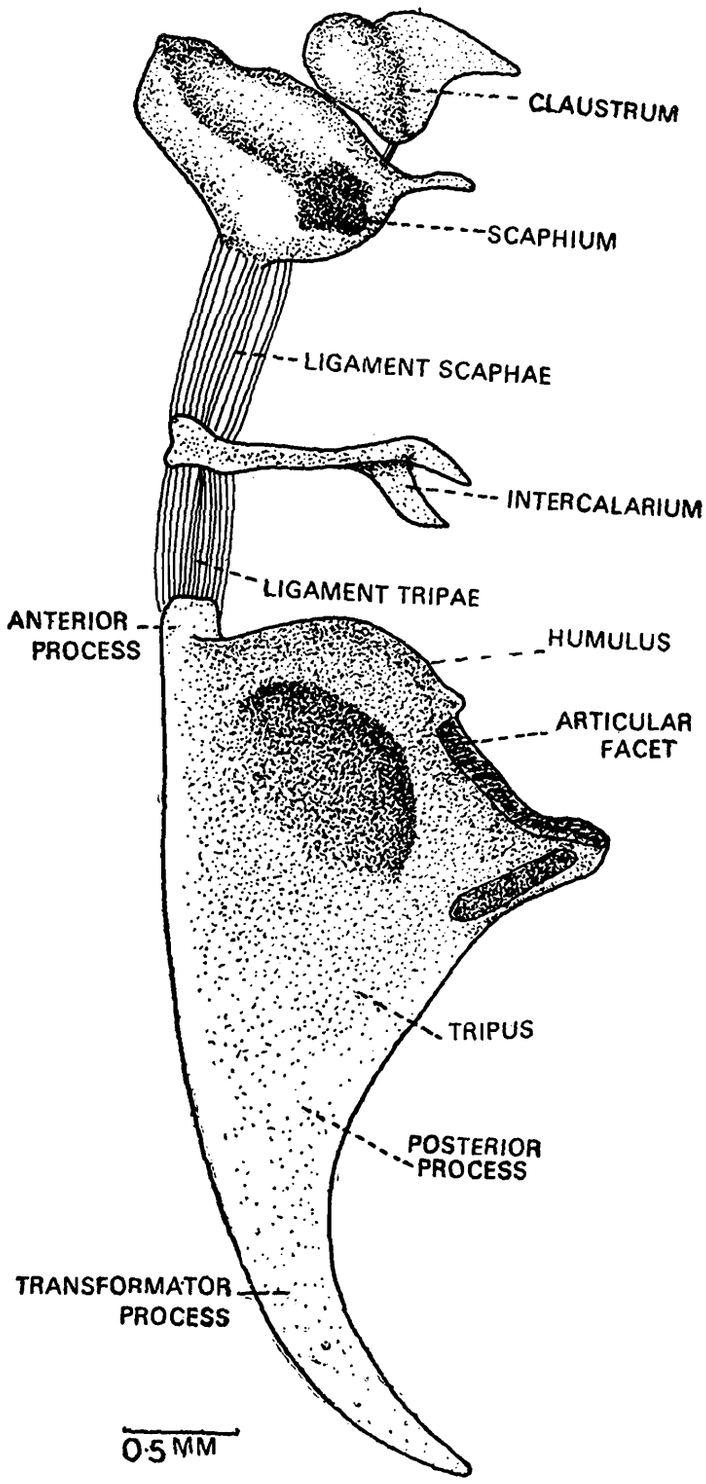


FIG 204

Pars Sustentaculum (Figs. 205-228) :

The pars sustentaculum is a modification of first foure vertebrae. The modification of the vertebrae has taken place in such a manner that a few of their elements have been transformed into the Weberian ossicles while the rest are united with one another to form the support.

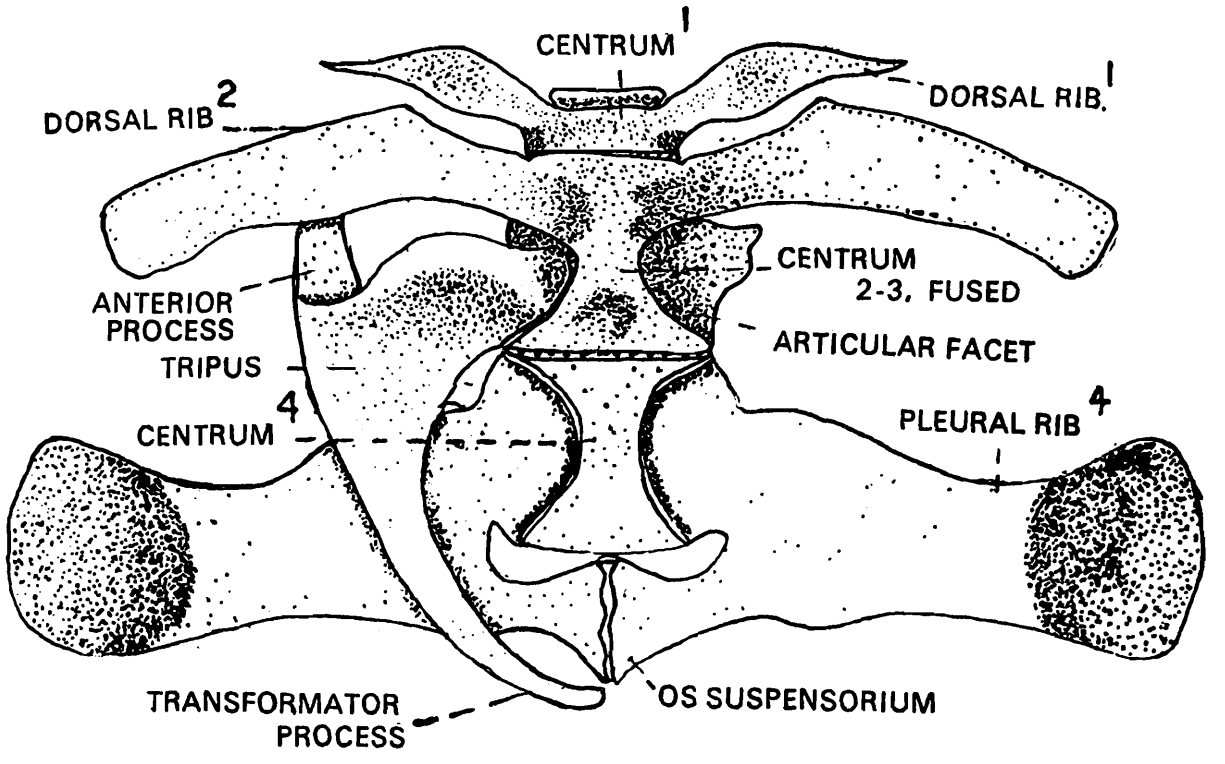


FIG 205

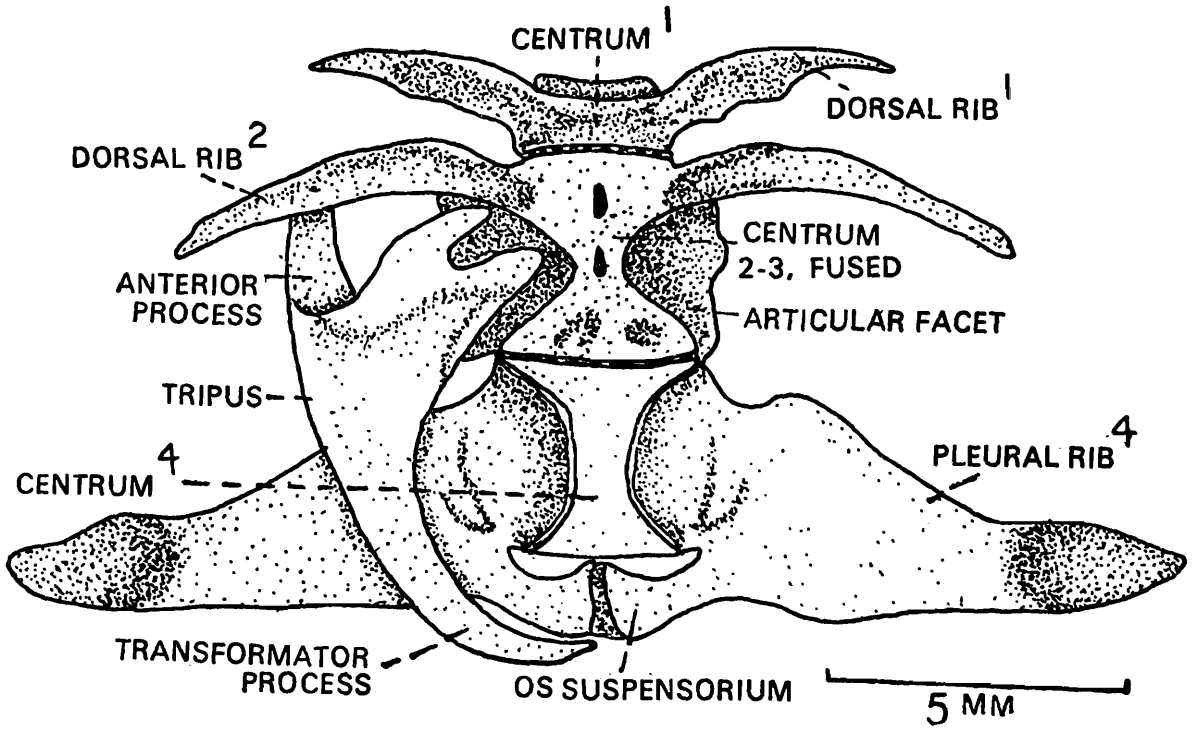


FIG 206

Figs. 205-216. Ventral aspects of the first four vertebrae with Weberian chain shown on one side of *Schizothorax richardsonii*, *Diptychus maculatus*, *Schizopygopsis stoliczkae*, *Ptycobarbus conirostris*, *Schizothoraichthy micropogon*, *S. esocinus*, *S. labiatus*, *Labeo dero*, *Schismatorhynchus nukta*, *Garra lamta*, *Aspidoparia morar* and *Rasbora daniconius* respectively.

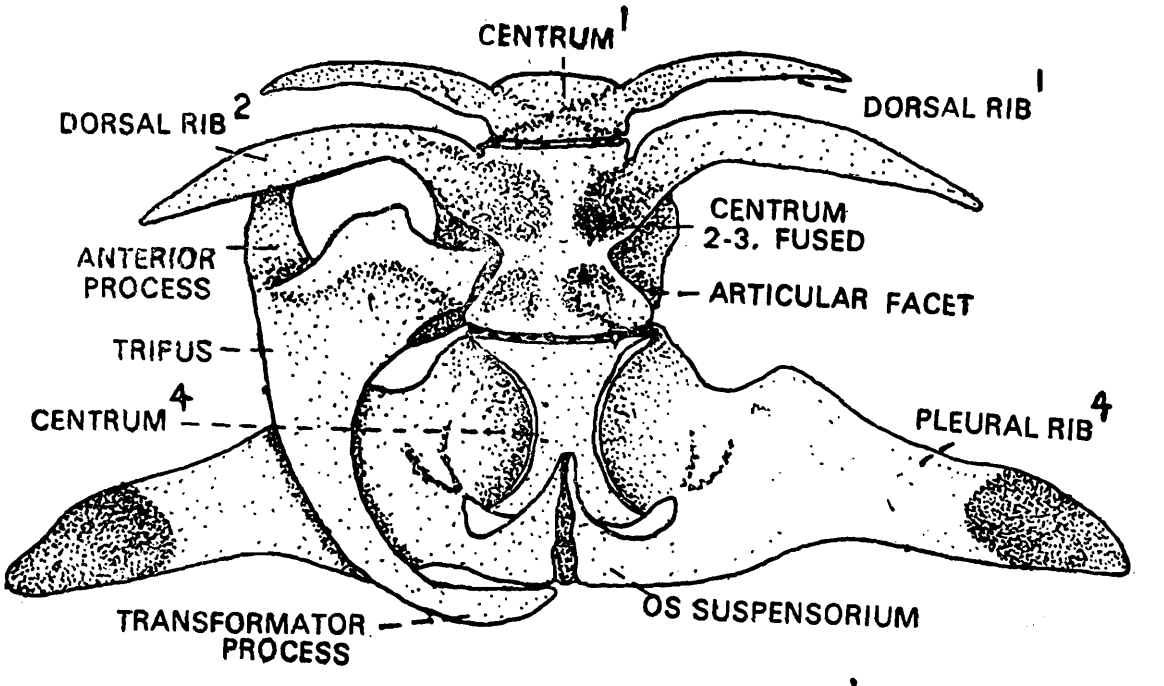


FIG 207

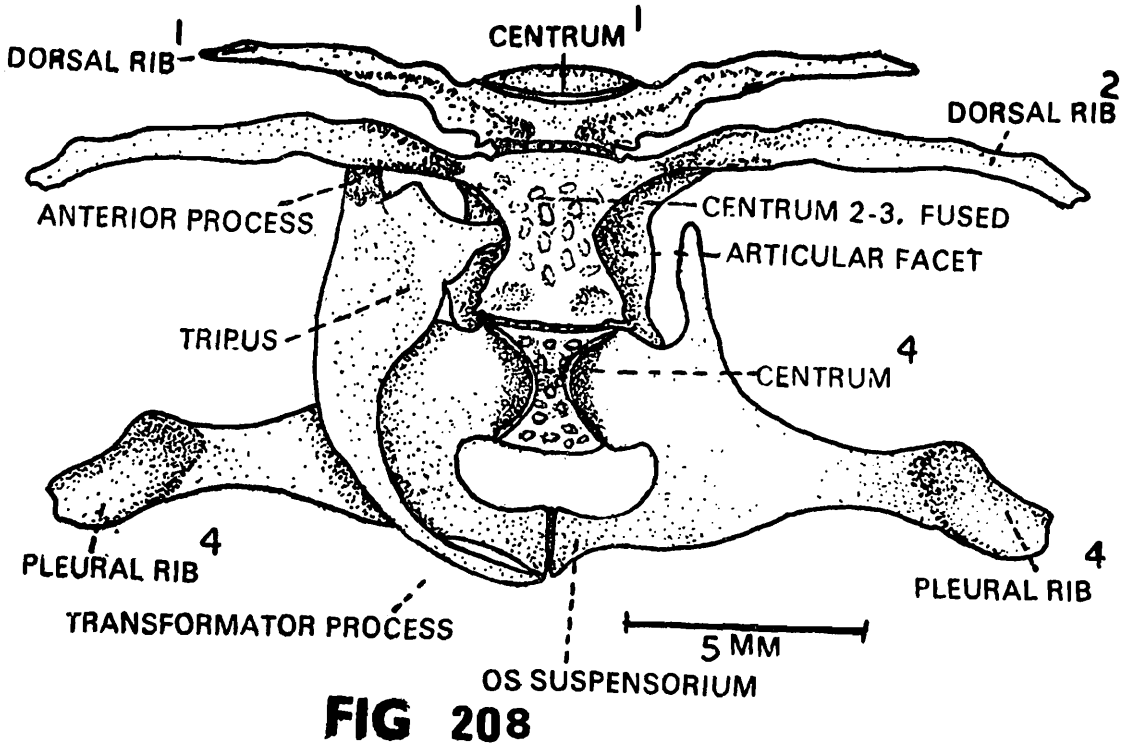


FIG 208

The first vertebra is represented only by the centrum and a pair of parapohysis. The centrum is considerably compressed anteroposteriorly and it remains fitted between the posterior concave end of basioccipital and the centrum of second vertebra. On the dorsal side of the centrum, there is a pit on each side which receives the ventral process arising from the condylar process of the respective scaphium. The centrum is

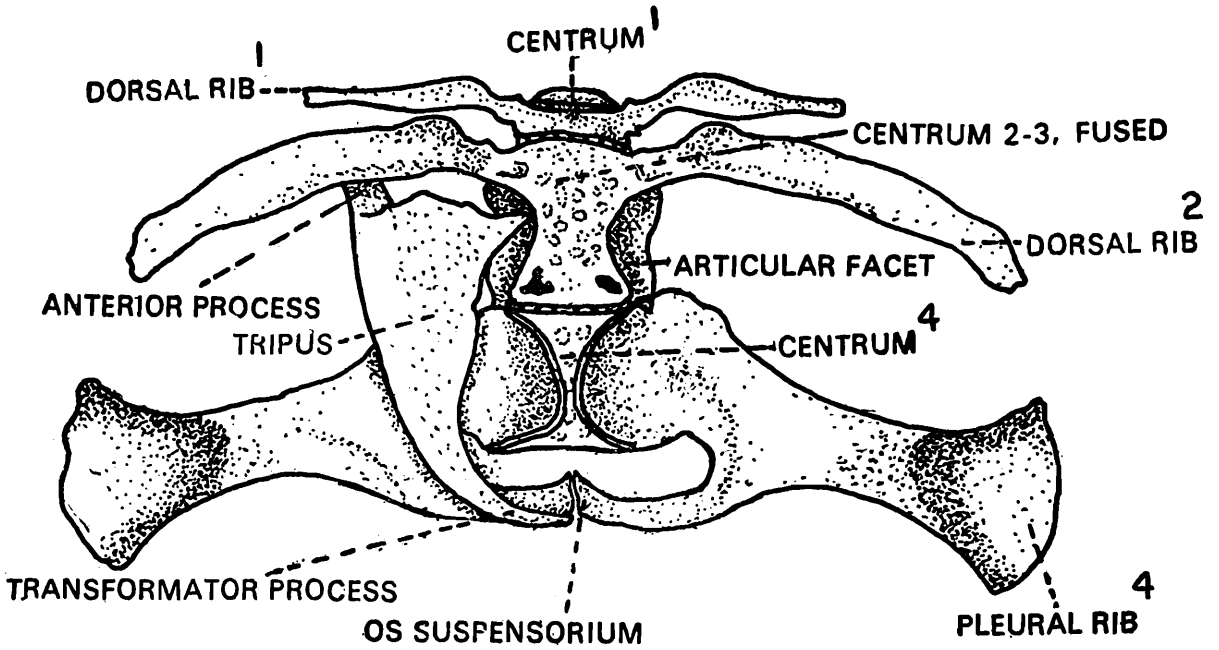


FIG 209

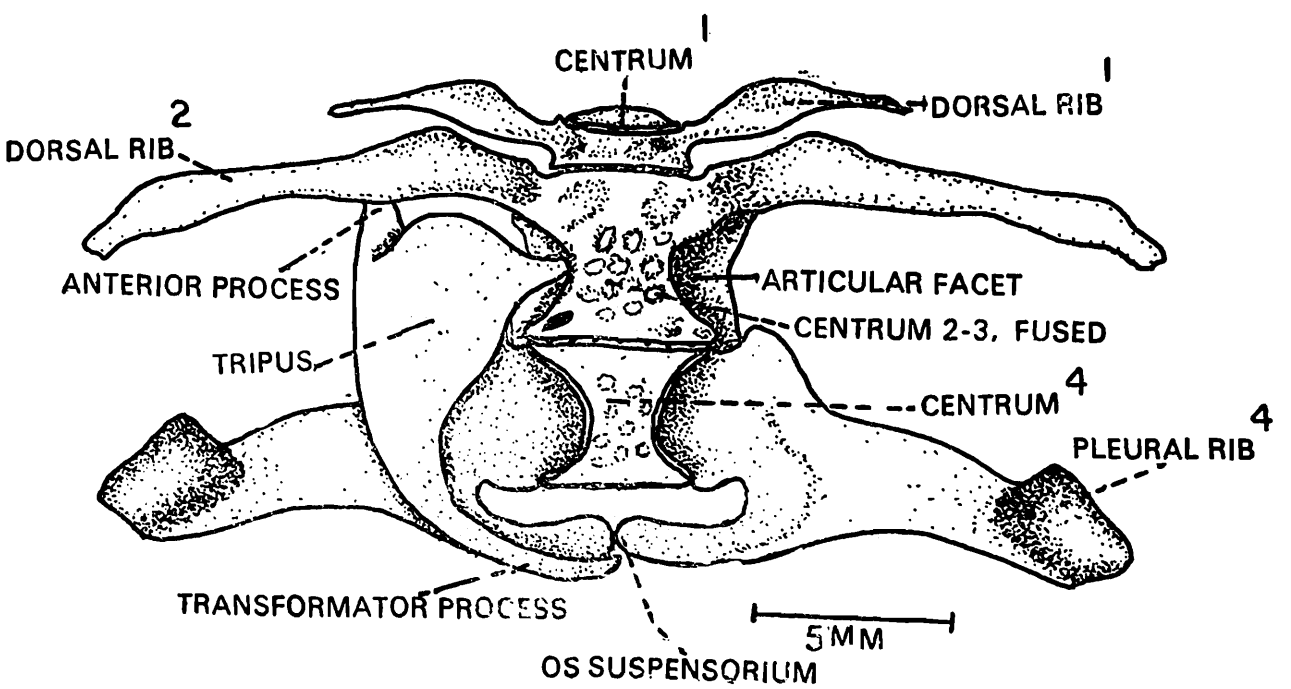


FIG 210

is planoconcave. The parapophyses of the first vertebra project horizontally outwards. In the schizothoracine genera, they are well developed and may be thicker or thinner than those of the second vertebra but always smaller than those of the latter. In the cyprinine genera they are almost equal to the length of the parapophyses of second vertebra while in the rasborine genera, they are extremely reduced than those of the succeeding ones.

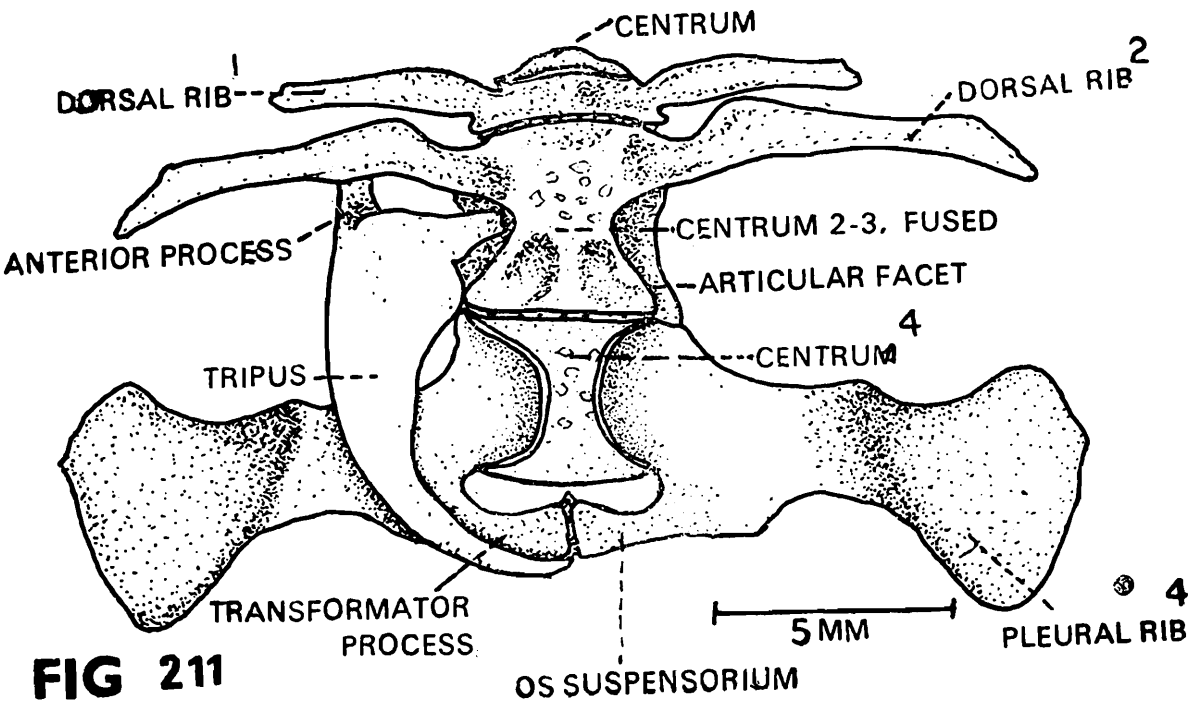


FIG 211

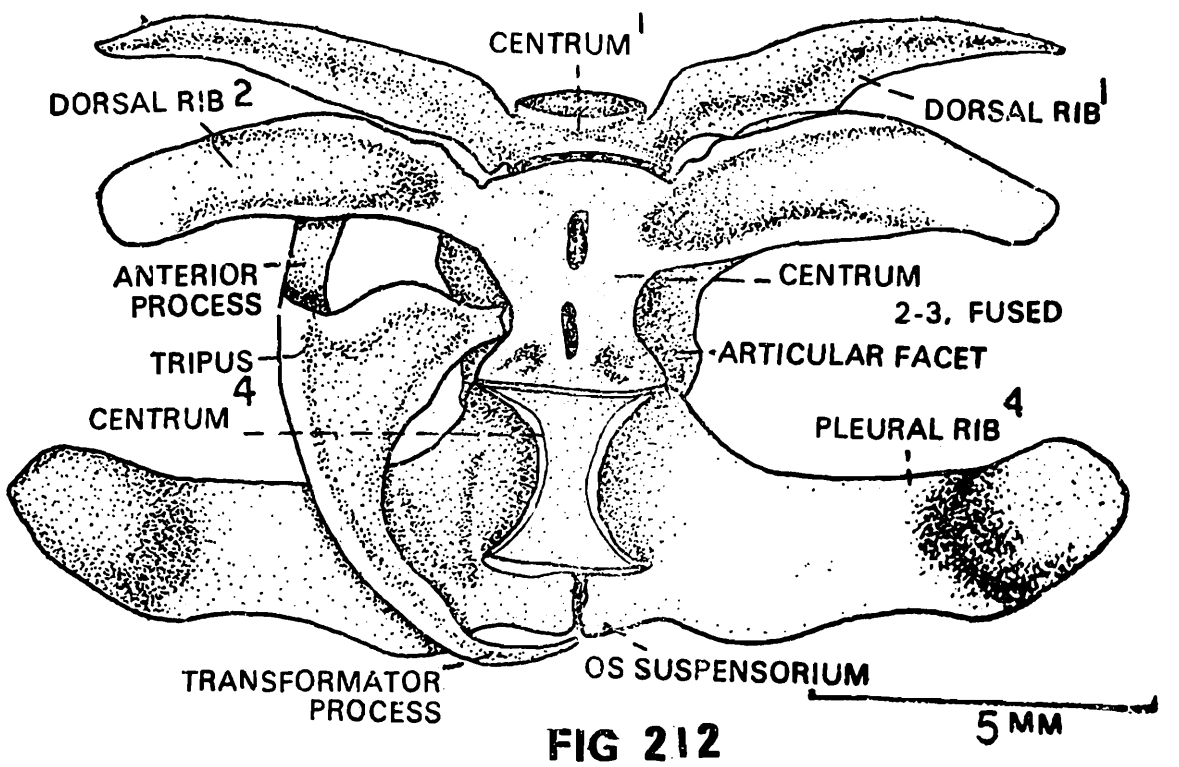


FIG 212

The centra of the second and third vertebrae have indistinguishably fused into a large, complex centrum which is amphicoelous. A pair of parapophyses originates horizontally outwards from the ventrolateral aspect of anterior region of the complex centrum. There are two neural plates. The aterior one represents the neural arch of the second vertebra

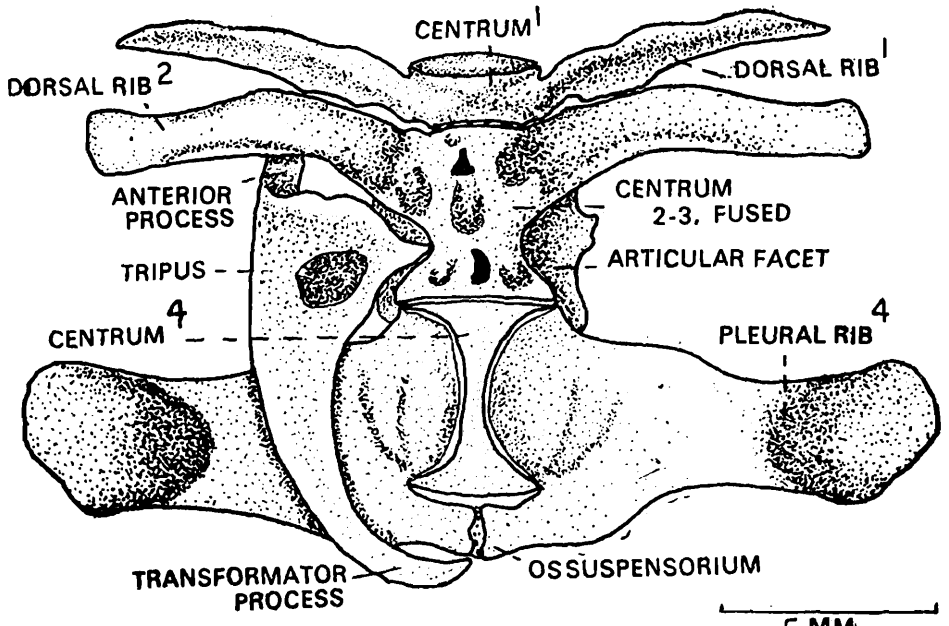


FIG 213

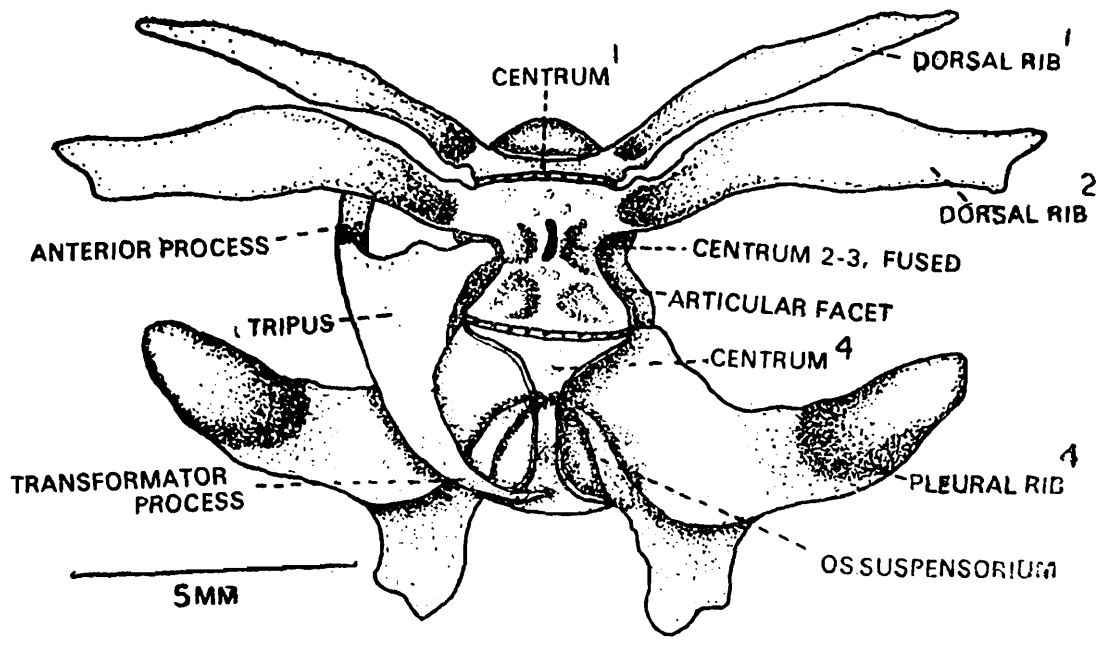


FIG 214

while the posterior one that of the third vertebra. They enclose the neural canal in this region. Attached dorsal to the neural arch of the third vertebra is a medial, vertical and flattened plate-the neural complex representing probably the fused neural spines of the second and third vertebrae. From the anterior edge of dorsal part of the complex neural spine, a beak-like process is given out which is pointed in *Diptychus maculatus*, *Schizothoraichthys labiatus* and *Garra lamta* while it is blunt in other species.

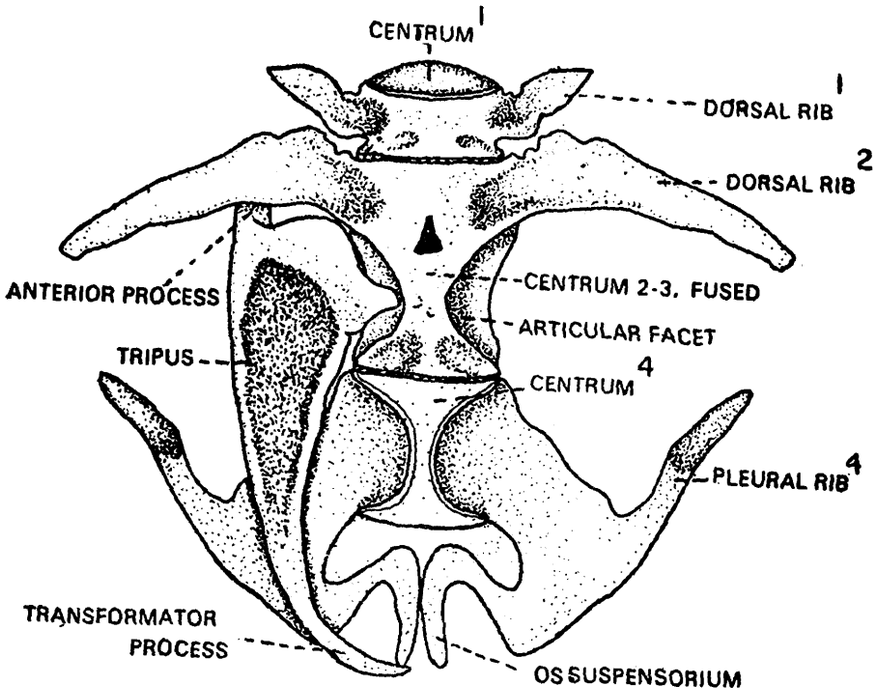


FIG 215

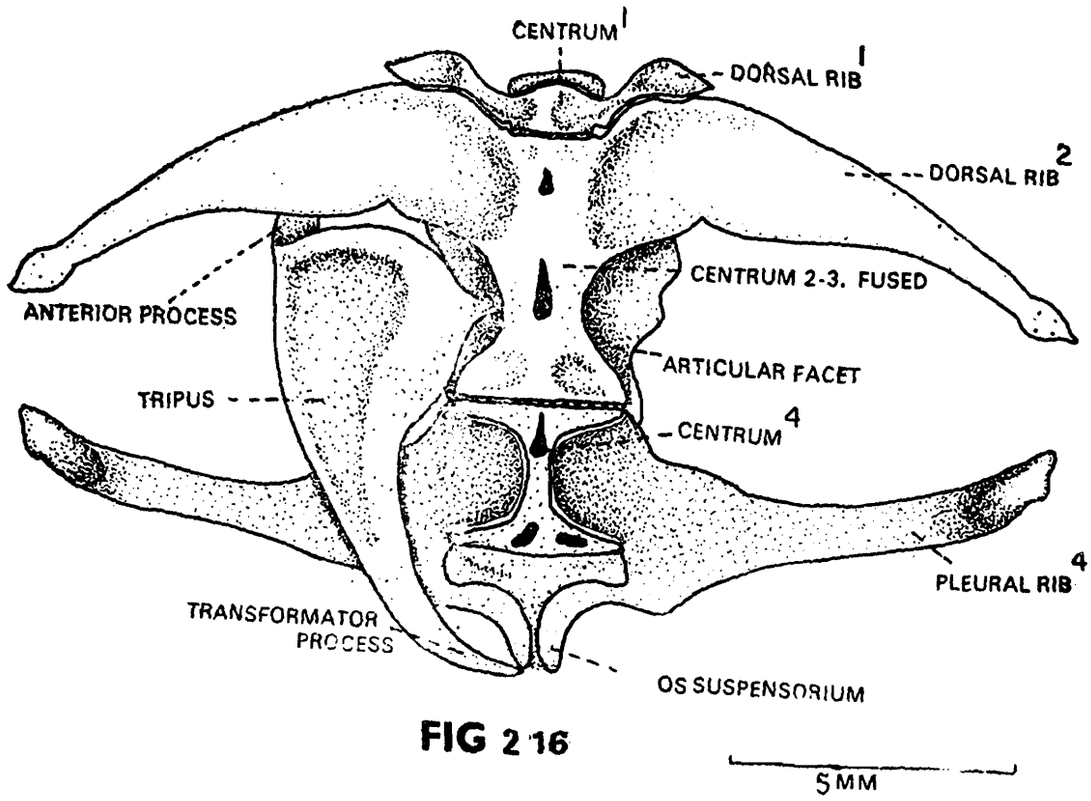


FIG 216

The anterior edge of the dorsal part of complex neural spine is square-cut in *Schizopygopsis stoliczkae* while it has no definite shape in others. The dorsal part of the complex neural spine is much expanded anteroposteriorly in *Schizopygopsis stoliczkae*, *Diptychus maculatus*, *Schizo-*

thoraichthys spp., *Labeo dero*, *Garra lamta* and *Schismatorhynchus nukta* while the posterior extension is missing in others. The neural spine of the first vertebra is apparently absent and has modified into the weberian ossicles. The complex neural spine articulates with the supraoccipital spine anteriorly and with the neural spine of the fourth vertebra posteriorly.

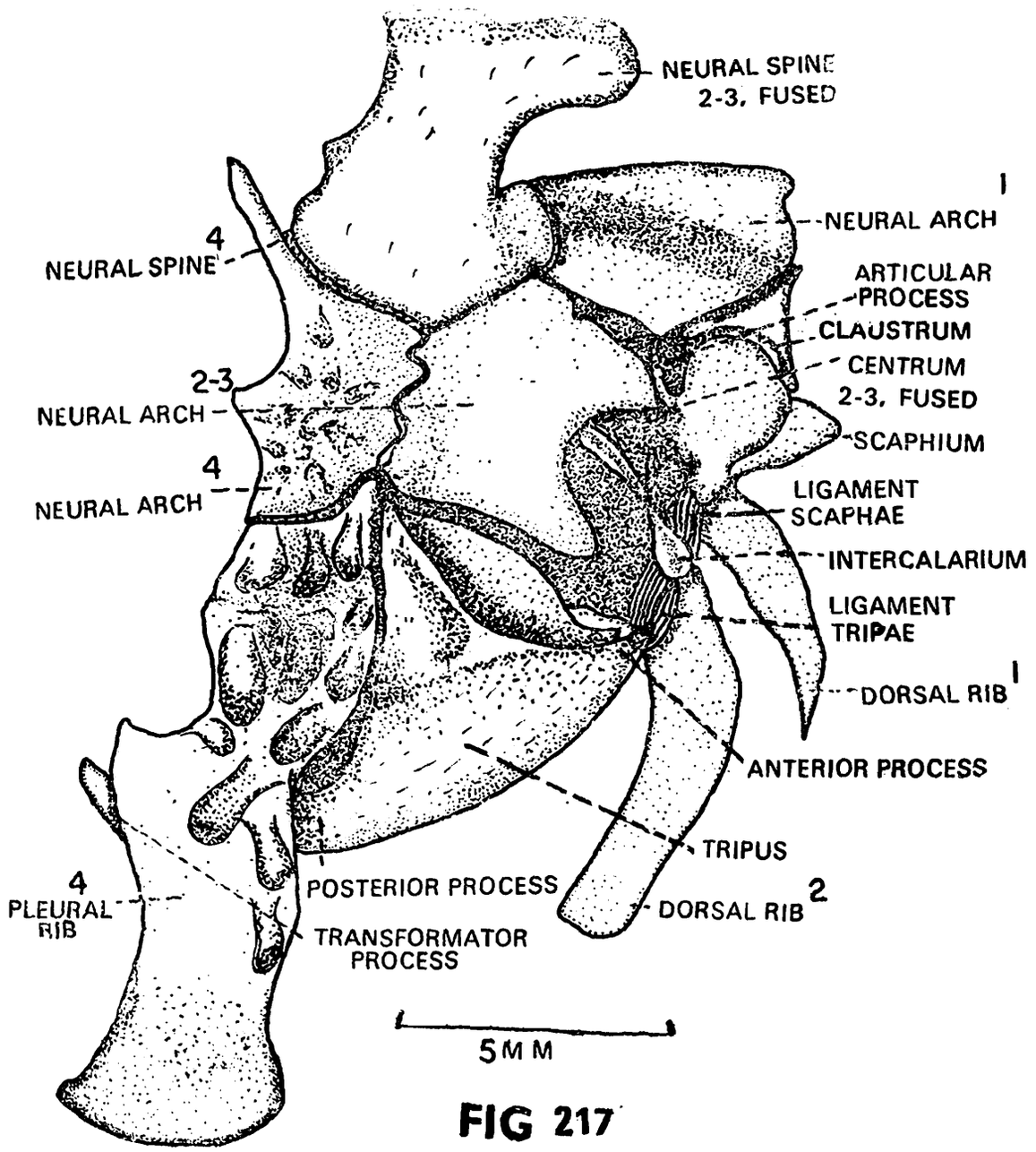


FIG 217

Figs. 217-228. Lateral, aspects of the first four vertebrae with Weberian chain of *Schizothorax richardsonii*, *Diptychus maculatus*, *Schizopygopsis stoliczkae*, *Ptycobarbus conirostris*, *Schizothoraichthys micropogon*, *S. esocinus*, *S.labiatus*, *Labeo*, *dero*,*Schismatorhynchus nukta*, *Garra lamta*, *Aspidoparia morar* and *Rasbora daniconius* respectively.

The fourth vertebra is composed of all the normal vertebral elements but in a modified form. From the ventrolateral aspect of the centrum of fourth vertebra originates a much developed and flattened parapophysis on each side. It runs ventroposteriorly and

covers and protects the transformator process of the tripus and the anterior part of the swim bladder. The ventral part of the tip of posterior bony process which forms the os suspensorium, helps in the attachment of anterior chamber of the swim bladder to the Weberian apparatus. The tip of the parapophysis of each side is expanded in *Schizothorax richardsonii*, *Schizothoraichthys* spp. and cyprinine genera whereas it is narrow in rest of the genera. In *Ptycobarbus conirostris*, a thin, splint-like process arises from the base of each fourth parapophysis. This process runs anteriorly on the dorsal side of the tripus

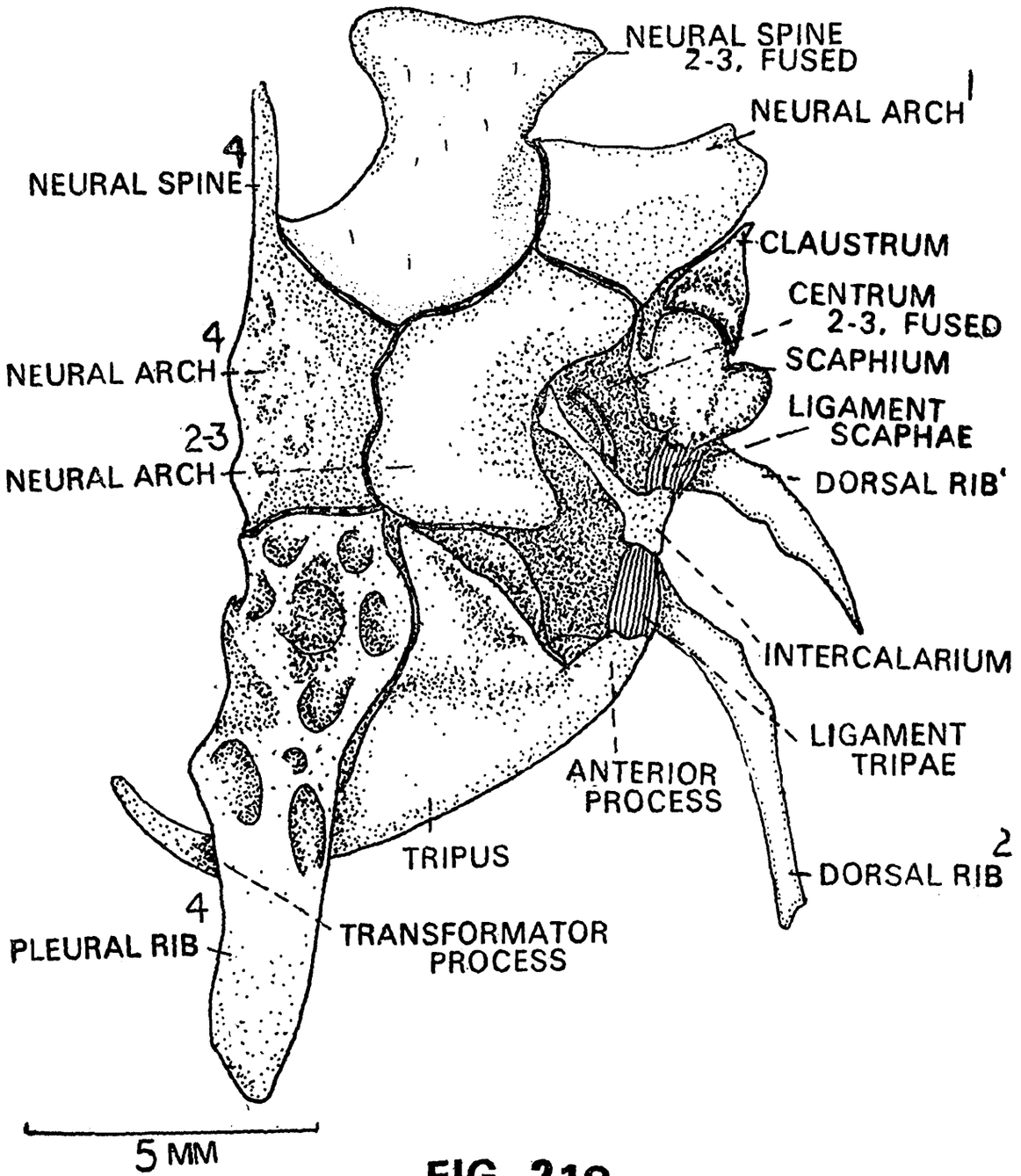


FIG 218

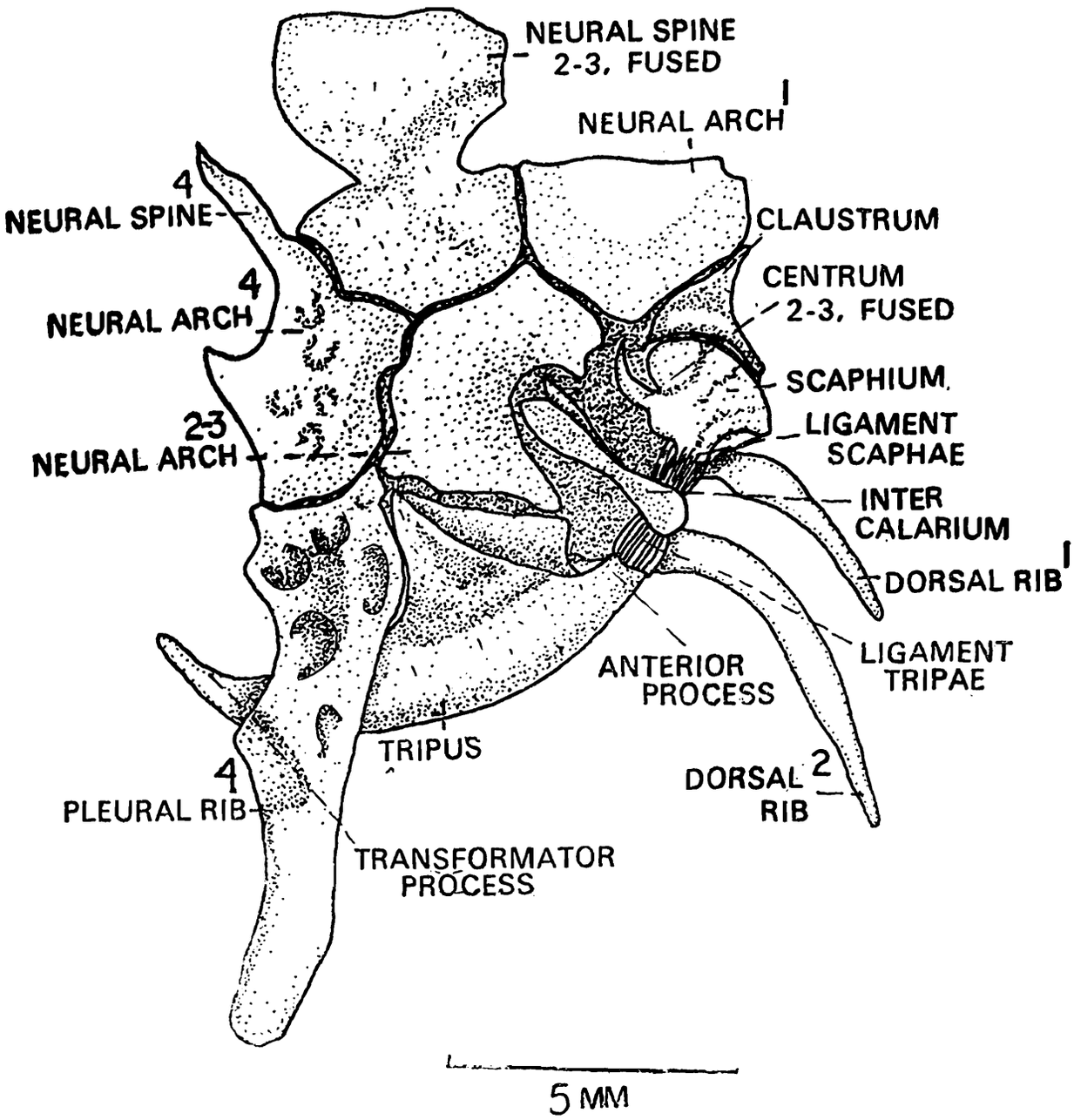


FIG 219

of its side. In *Schizothoraichthys* spp., this process is very rudimentary while in rest of the speeies, there is hardly any indication of such a process.

Each of suspensorium is an anteriorly curved process and the transformator process runs behind it and posterior to it. It is thicker in *Schizothorax richardsonii*, *Schizopygopsis stoliczkae* and *Diptychus maculatus* while it is thinner in *Schizothoraichthys* spp., *Ptycobarus conirostris*, *Aspidoparia morar* and *Garra lamta*. The os suspensorium is of moderate thickness in *Labeo dero* and *Schismatorhynchus nukta*. It is posteriorly directed in *Ptycobarbus conirostris* and *Schizothoraichthys* spp., while ventrally directed in others.

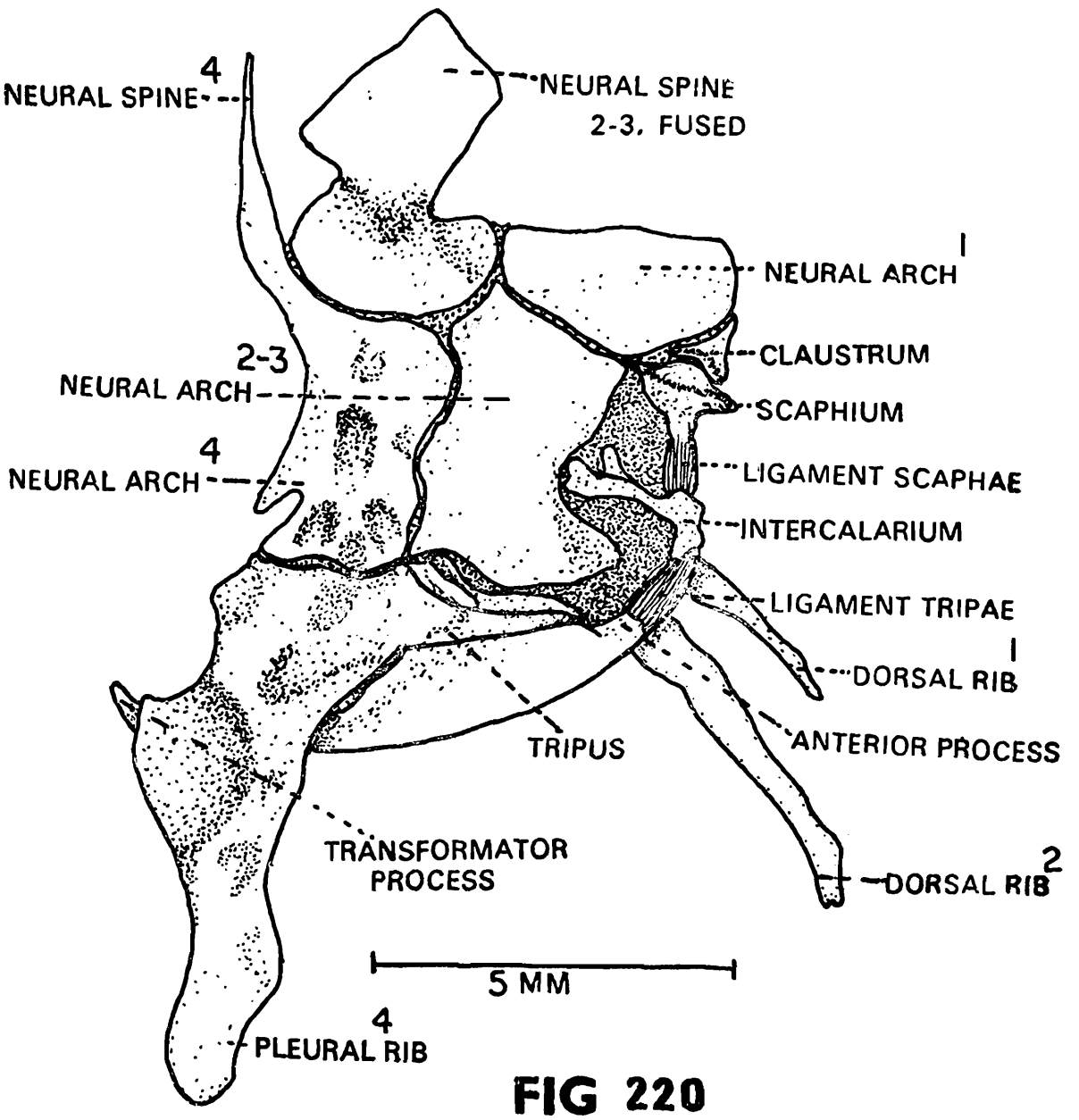


FIG 220

Swim bladder (Figs. 229-240) : It lies dorsal to the alimentary canal, immediately beneath the vertebral column and is a bipartite, elogated structure consisting of two chambers : an anterior and a posterior. The two are separated by a constriction in between them.

The anterior chamber is small and oval in shape and is connected to the internal ear through a chain of ossicles. The posterior chamber is larger and is connected to the oesophagus by means of a small pneumatic duct.

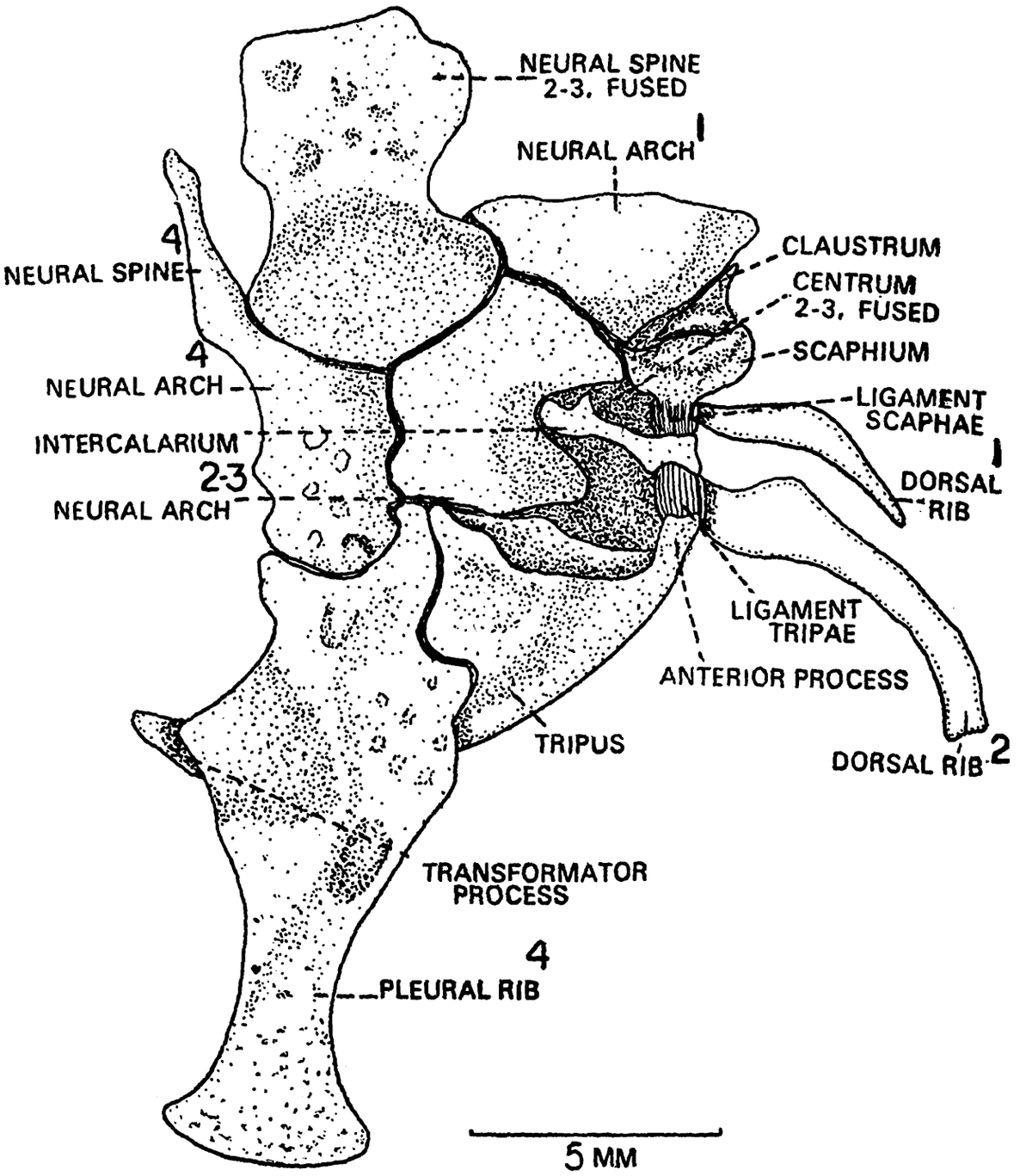

NEURAL SPINE
2-3, FUSED
NEURAL ARCH
1
4
NEURAL SPINE
CLAUSTRUM
CENTRUM
2-3, FUSED
SCAPHIUM
4
NEURAL ARCH
LIGAMENT
SCAPHAE
INTERCALARIUM
1
DORSAL
RIB
2-3
NEURAL ARCH
LIGAMENT
TRIPAE
ANTERIOR PROCESS
TRIPUS
DORSAL RIB 2
TRANSFORMATOR
PROCESS
4
PLEURAL RIB
5 MM

FIG 221

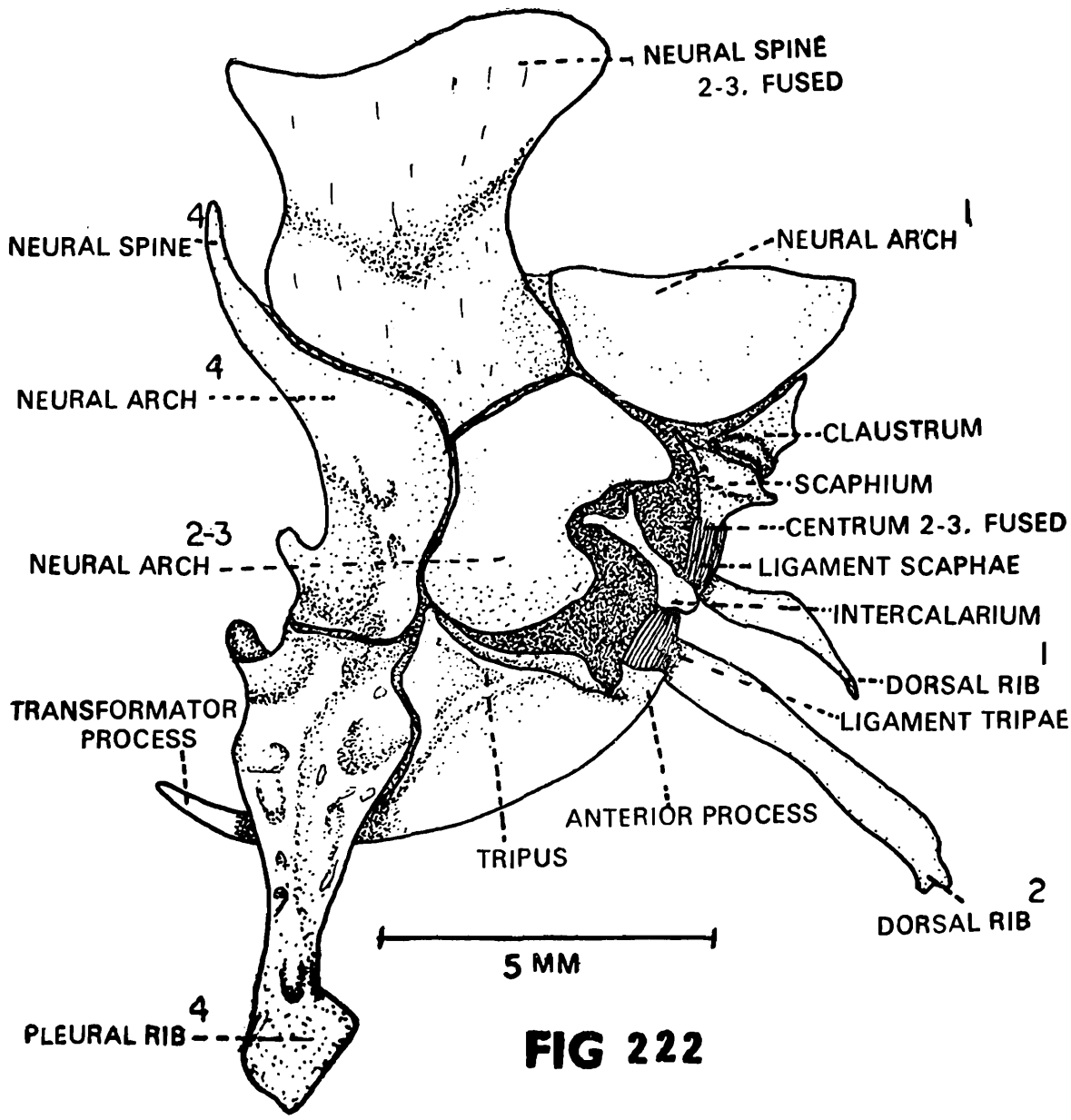

NEURAL SPINE
2-3. FUSED
4
NEURAL SPINE
NEURAL ARCH
1
4
NEURAL ARCH
CLAUSTRUM
SCAPHIUM
2-3
NEURAL ARCH
CENTRUM 2-3. FUSED
LIGAMENT SCAPHAE
INTERCALARIUM
1
DORSAL RIB
TRANSFORMATOR
PROCESS
LIGAMENT TRIPAE
ANTERIOR PROCESS
TRIPUS
2
DORSAL RIB
5 MM
4
PLEURAL RIB

FIG 222

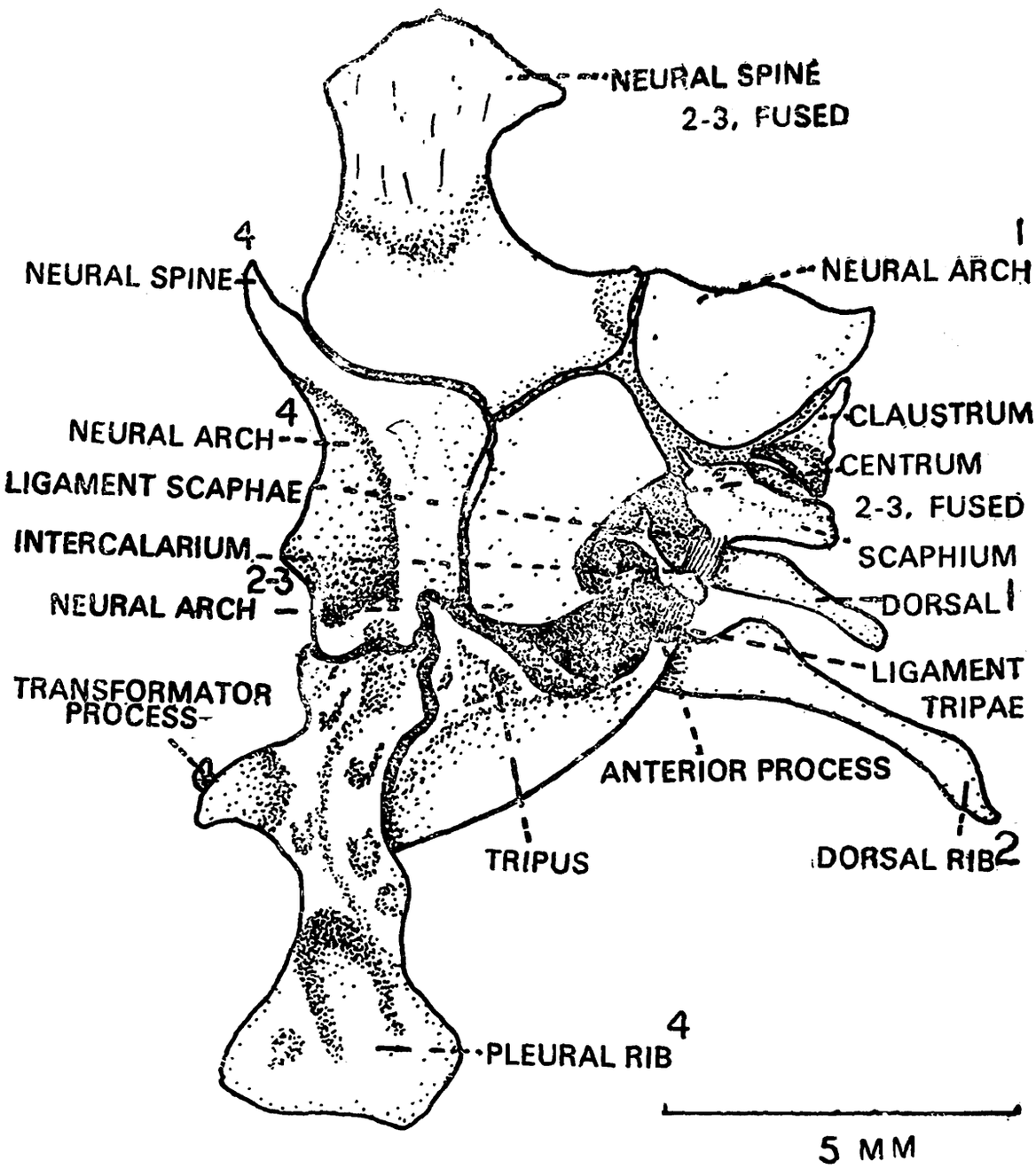

NEURAL SPINE
2-3, FUSED
4
NEURAL SPINE
1
NEURAL ARCH
4
NEURAL ARCH
CLAUSTRUM
CENTRUM
2-3, FUSED
LIGAMENT SCAPHAE
INTERCALARIUM
SCAPHIUM
2-3
NEURAL ARCH
DORSAL
LIGAMENT
TRIPAE
TRANSFORMATOR
PROCESS
ANTERIOR PROCESS
TRIPUS
DORSAL RIB
2
4
PLEURAL RIB
5 MM

FIG 223

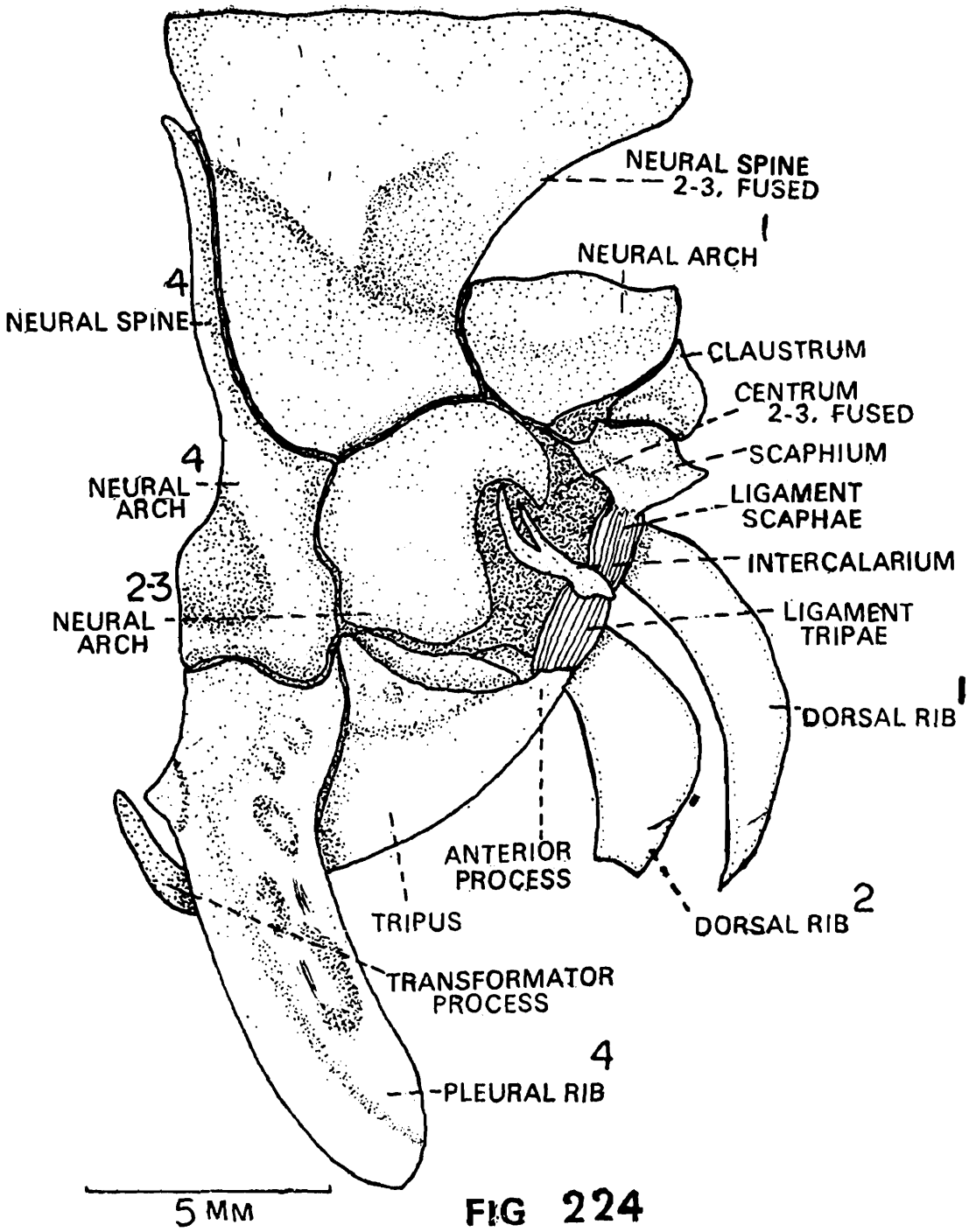

NEURAL SPINE
2-3, FUSED
1
NEURAL ARCH
4
NEURAL SPINE
CLAUSTRUM
CENTRUM
2-3, FUSED
SCAPHIUM
4
NEURAL
ARCH
LIGAMENT
SCAPHAE
INTERCALARIUM
2-3
NEURAL
ARCH
LIGAMENT
TRIPAE
DORSAL RIB
1
ANTERIOR
PROCESS
TRIPUS
DORSAL RIB
2
TRANSFORMATOR
PROCESS
4
PLEURAL RIB
5 MM

FIG 224

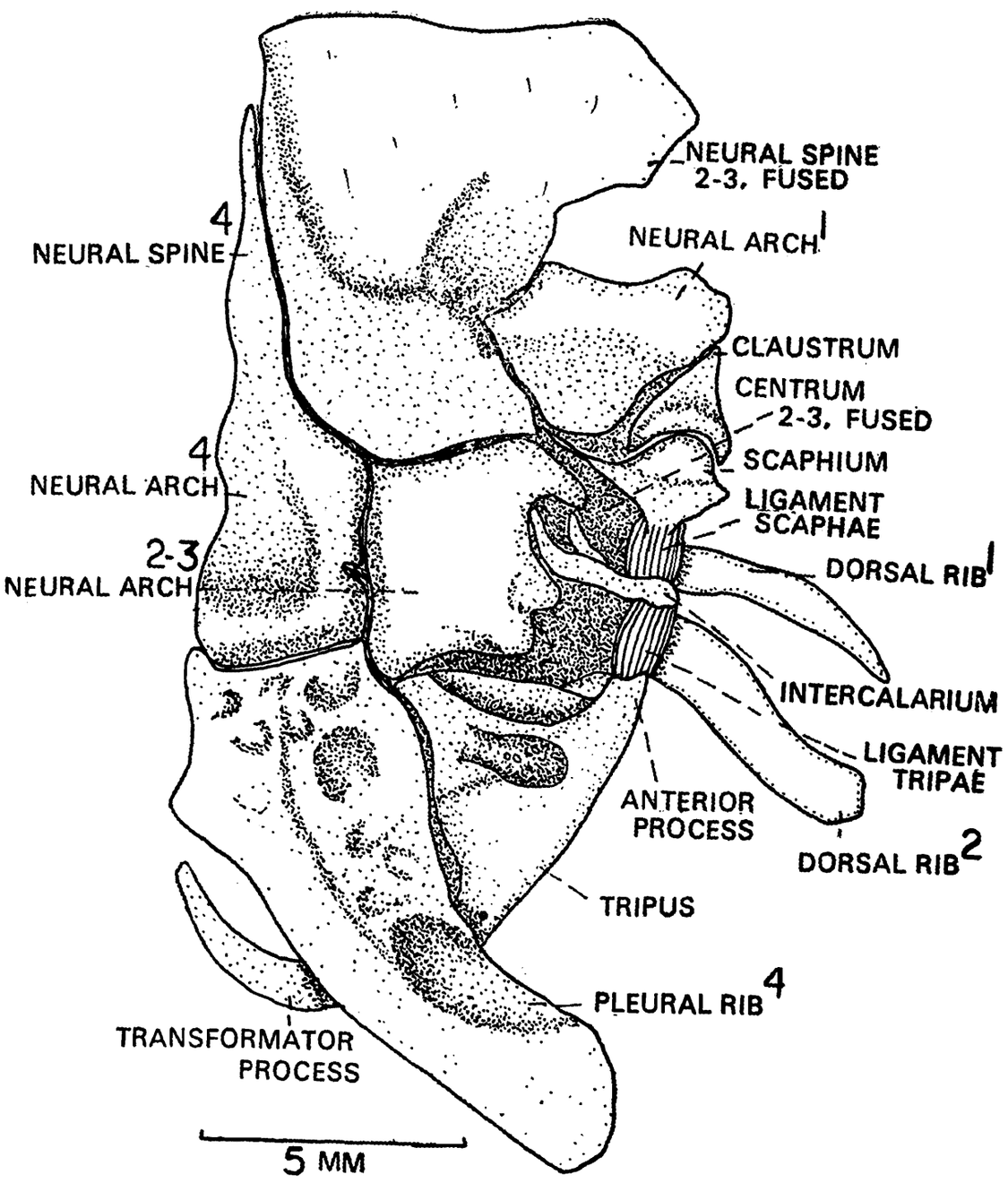

NEURAL SPINE 2-3, FUSED
4
NEURAL SPINE
NEURAL ARCH 1
CLAUSTRUM
CENTRUM 2-3, FUSED
4
NEURAL ARCH
SCAPHIUM
LIGAMENT SCAPHAE
2-3
NEURAL ARCH
DORSAL RIB 1
INTERCALARIUM
LIGAMENT TRIPAE
ANTERIOR PROCESS
DORSAL RIB 2
TRIPUS
PLEURAL RIB 4
TRANSFORMATOR PROCESS
5 MM

FIG 2.25

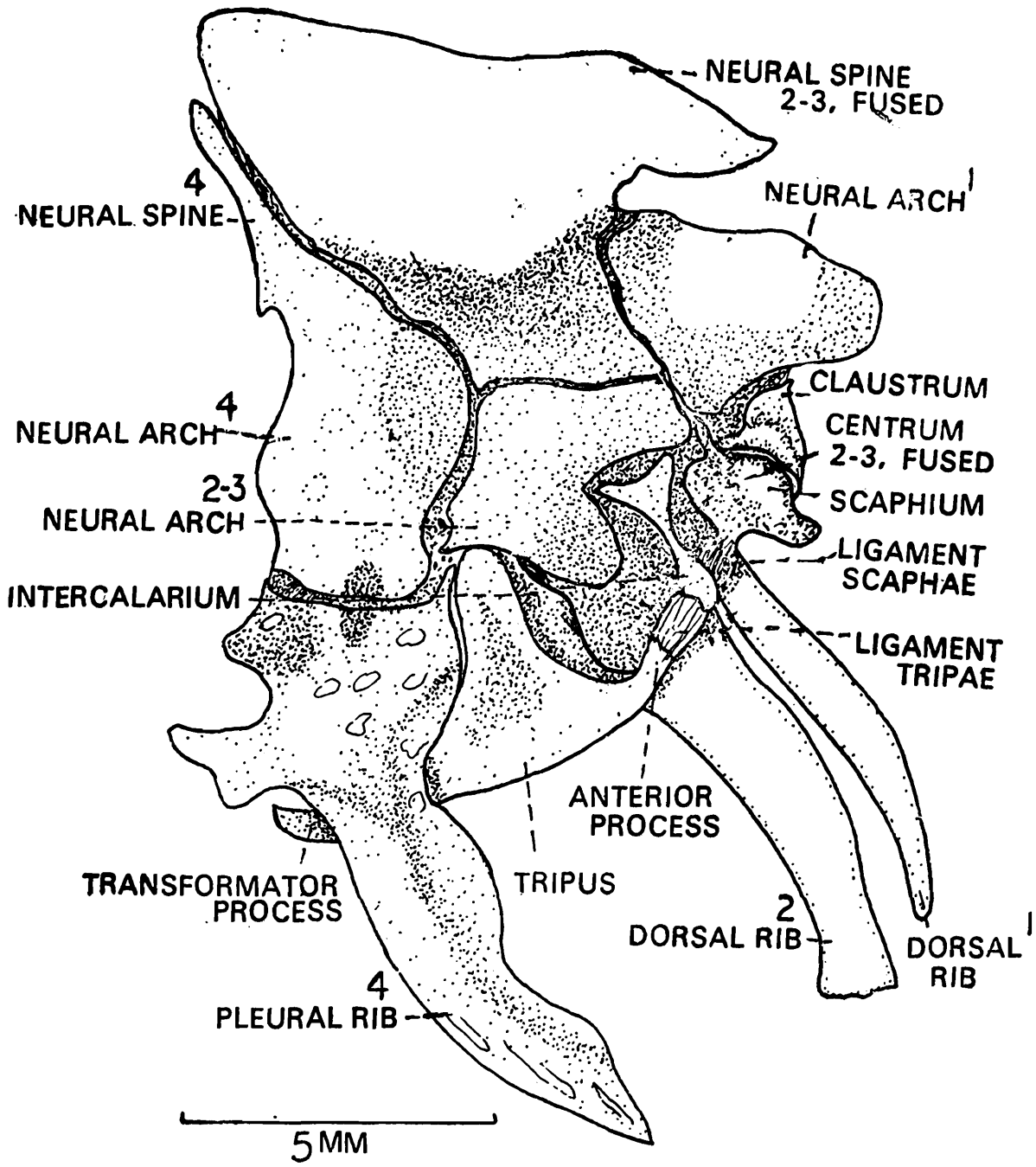

NEURAL SPINE 2-3, FUSED
4 NEURAL SPINE
NEURAL ARCH 1
CLAUSTRUM
4 NEURAL ARCH
CENTRUM 2-3, FUSED
2-3 NEURAL ARCH
SCAPHIUM
LIGAMENT SCAPHAE
INTERCALARIUM
LIGAMENT TRIPAE
ANTERIOR PROCESS
TRANSFORMATOR PROCESS
TRIPUS
2 DORSAL RIB
DORSAL RIB 1
4 PLEURAL RIB
5 MM

FIG 226

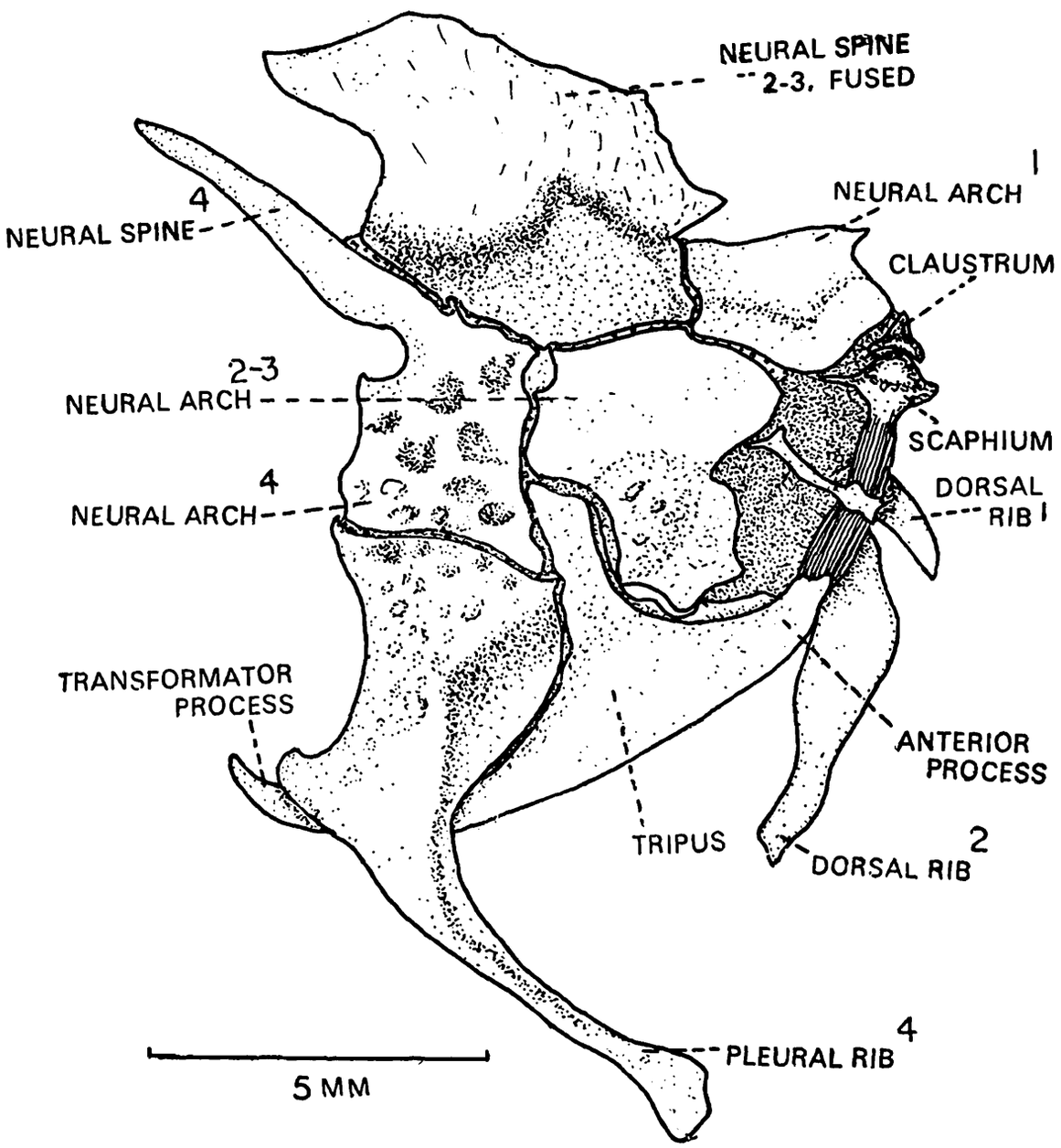

NEURAL SPINE
2-3, FUSED
1
NEURAL ARCH
4
NEURAL SPINE
CLAUSTRUM
2-3
NEURAL ARCH
SCAPHIUM
4
NEURAL ARCH
DORSAL
RIB 1
TRANSFORMATOR
PROCESS
ANTERIOR
PROCESS
TRIPUS
2
DORSAL RIB
4
PLEURAL RIB
5 MM

FIG 227

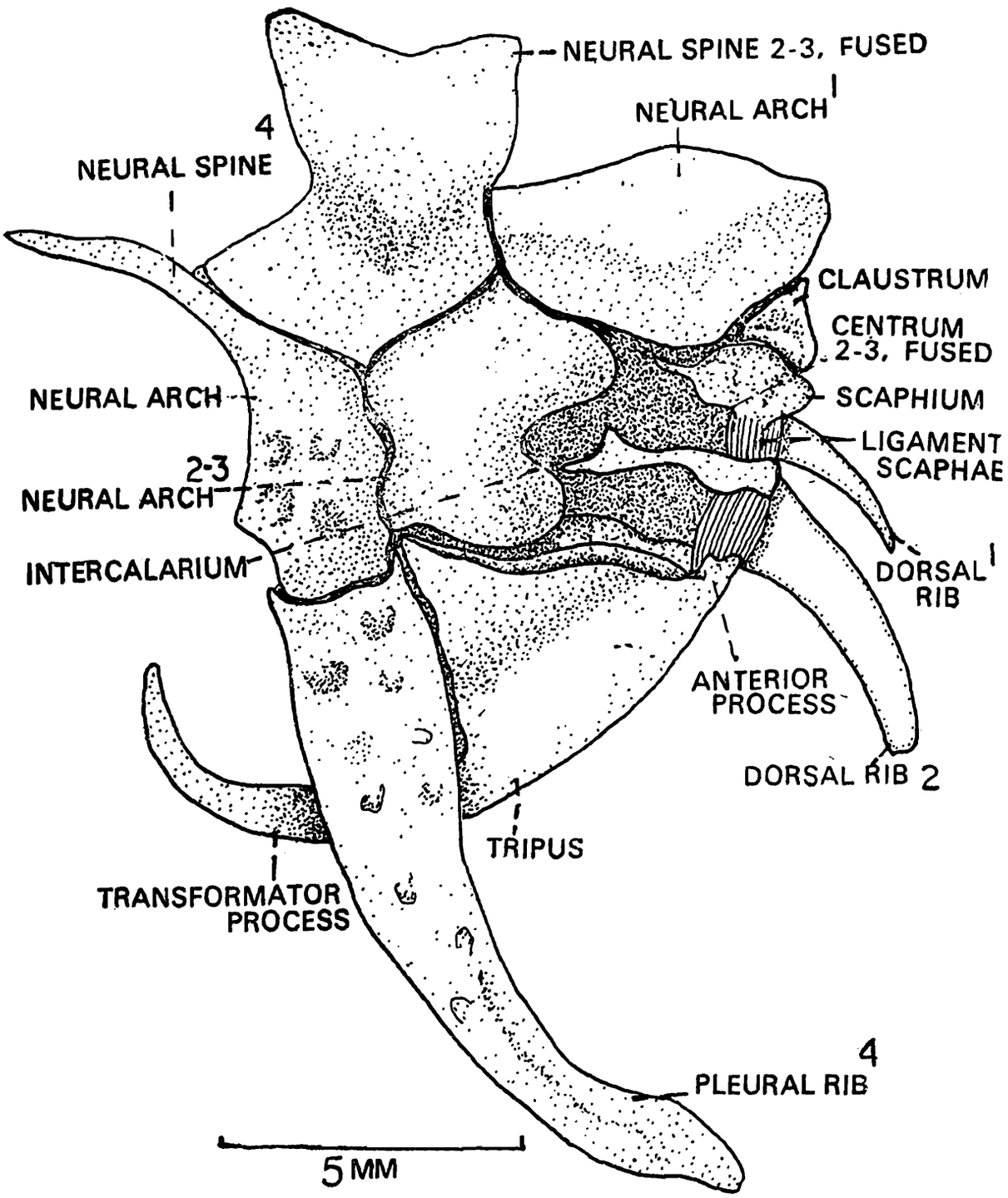

NEURAL SPINE 2-3, FUSED
NEURAL ARCH 1
4
NEURAL SPINE
CLAUSTRUM
CENTRUM 2-3, FUSED
NEURAL ARCH
SCAPHIUM
LIGAMENT SCAPHAE
2-3
NEURAL ARCH
INTERCALARIUM
DORSAL RIB 1
ANTERIOR PROCESS
DORSAL RIB 2
TRIPUS
TRANSFORMATOR PROCESS
4
PLEURAL RIB
5 MM

FIG 228

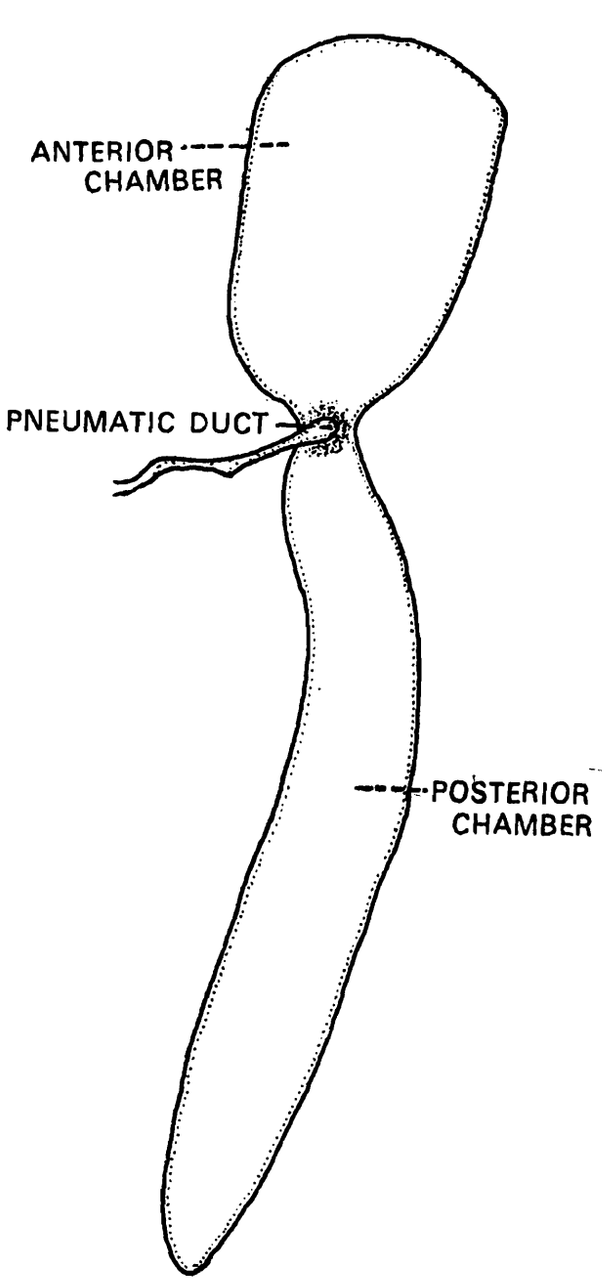


FIG 229

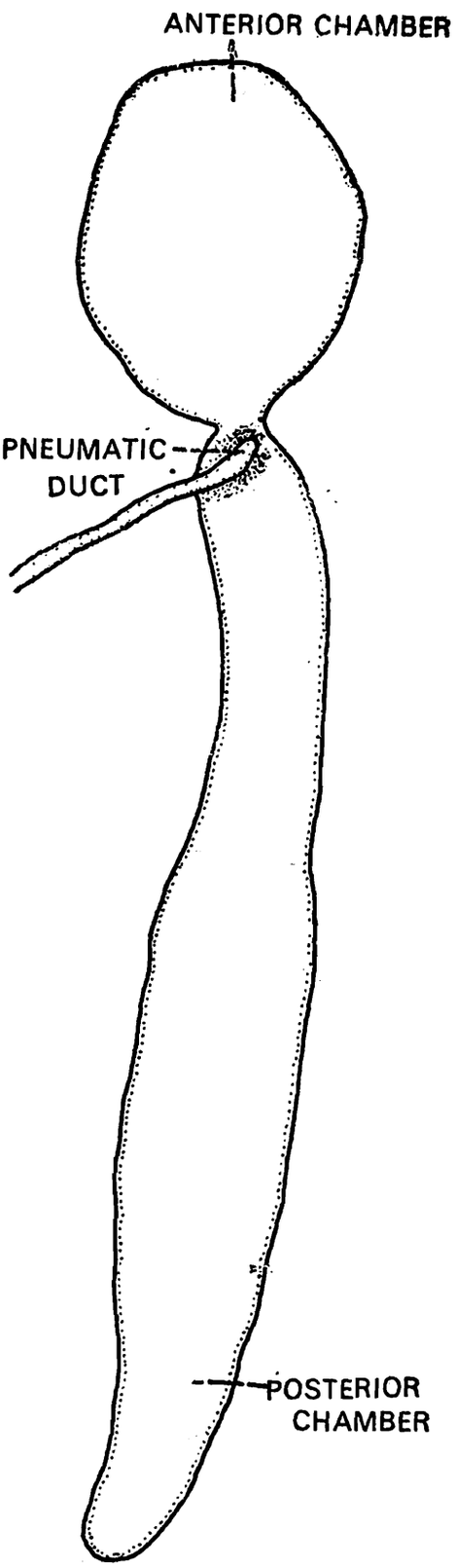


FIG 230

Figs. 229-240. Swim bladders of *Schizothorax richardsonii*, *Diptychus maculatus* *Schizopygopsis stoliczkae*, *Ptycobarbus conirostris* *Schizothoraichthys micropogon*, *S. esocinus*, *S. labiatus*, *Labeo dero*, *Schismatorhynchus nukta*, *Garra lamta*, *Aspidoparia morar* and *Rasbora daniconius* respectively.

C. Girdles

Pectoral girdle :

Each girdle is a well ossified, roughly an 'L'—shaped with the upper arm of the 'L' constituted by the postemporal, the supracleithrum and the dorsal horizontal limb of the cleithrum while the lower arm of the

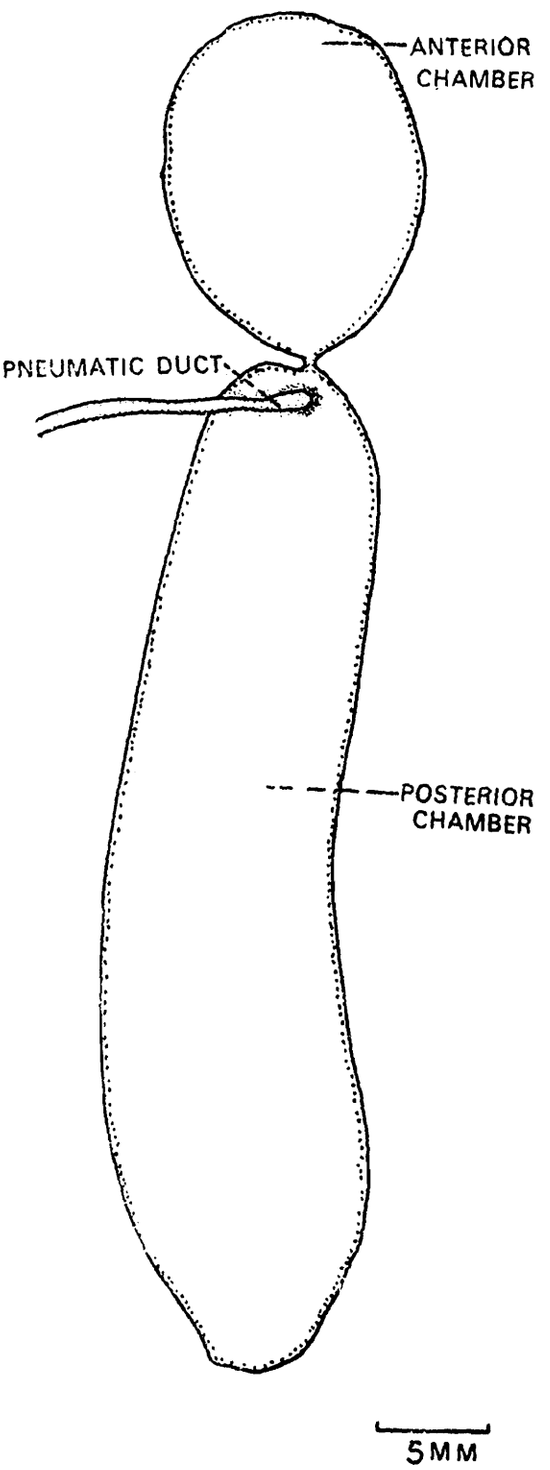


FIG 231

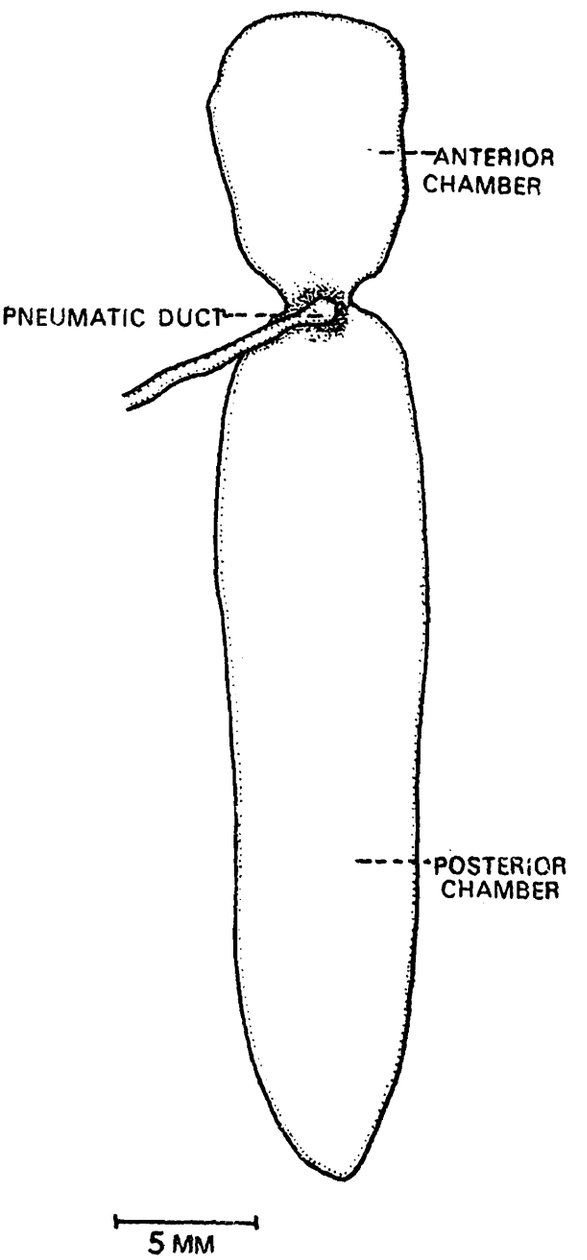


FIG 232

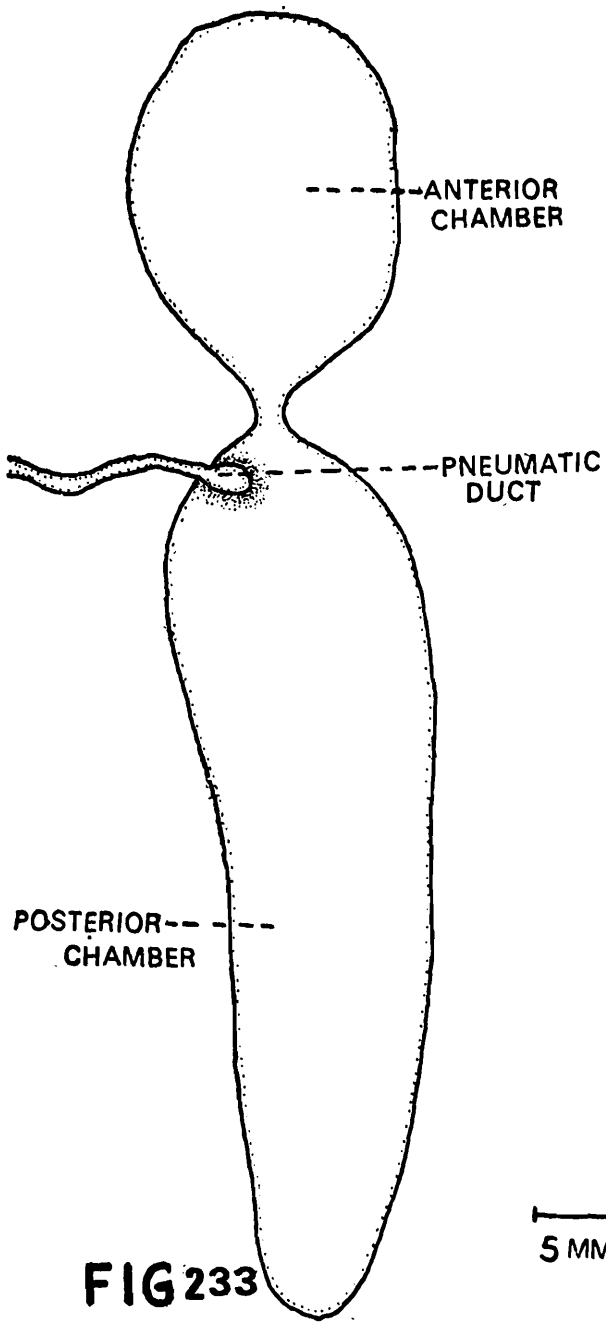


FIG 233

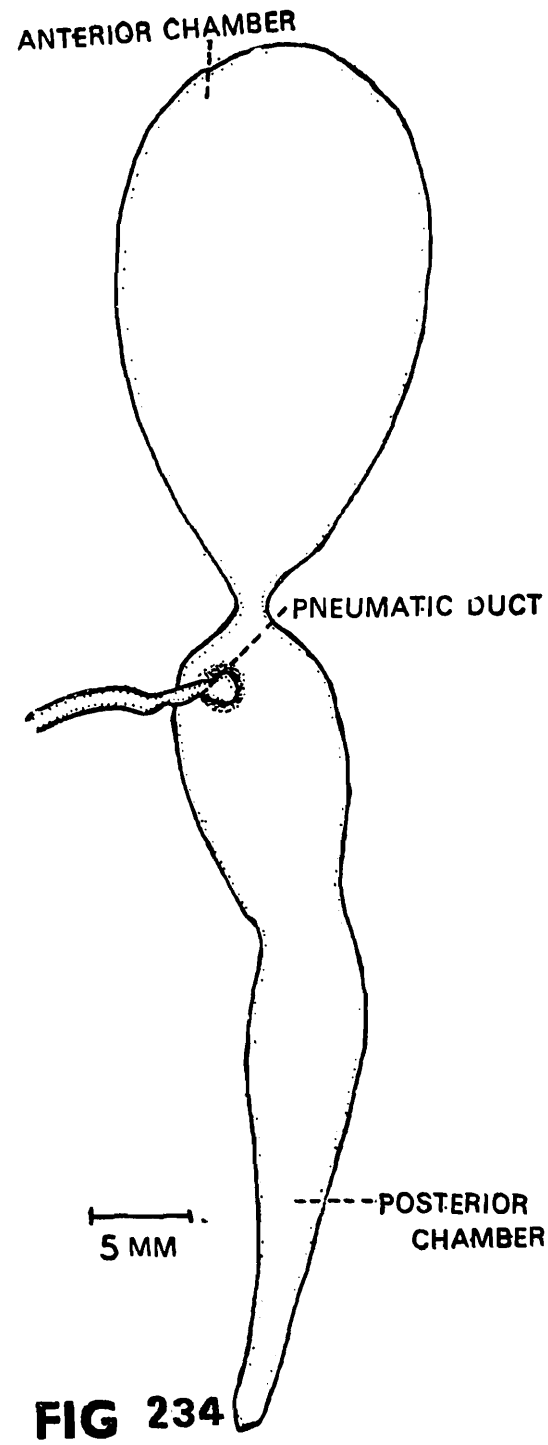


FIG 234

'L' is formed by the coracoid, mesocoracoid, scapula and the ventral horizontal limb of the cleithrum. The pectoral girdles of the two sides extend from the posterolateral corners of the neurocranium, ventrally to the base of pharyngeal region where the ventral tips of the girdles meet each other and form a pectoral symphysis which is bounded by strong ligaments. The posterior angle at the spmphysis is roughly 30°-40°.

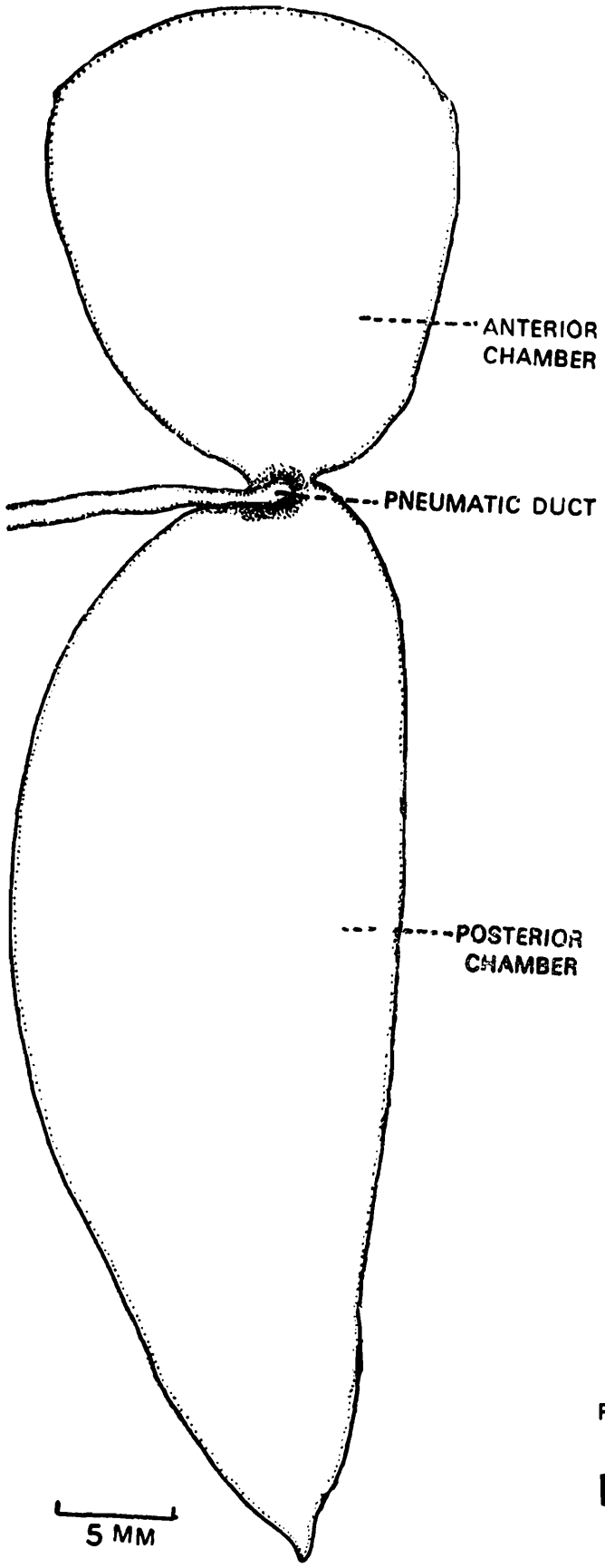


FIG 236

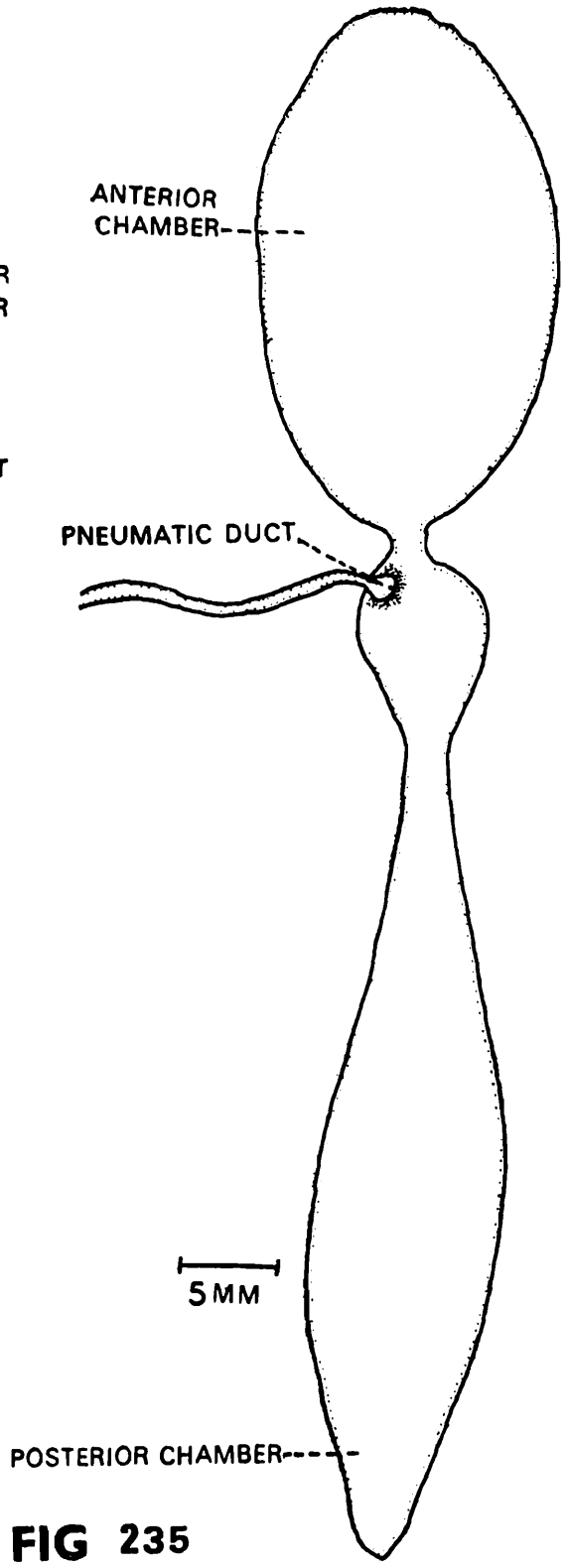


FIG 235

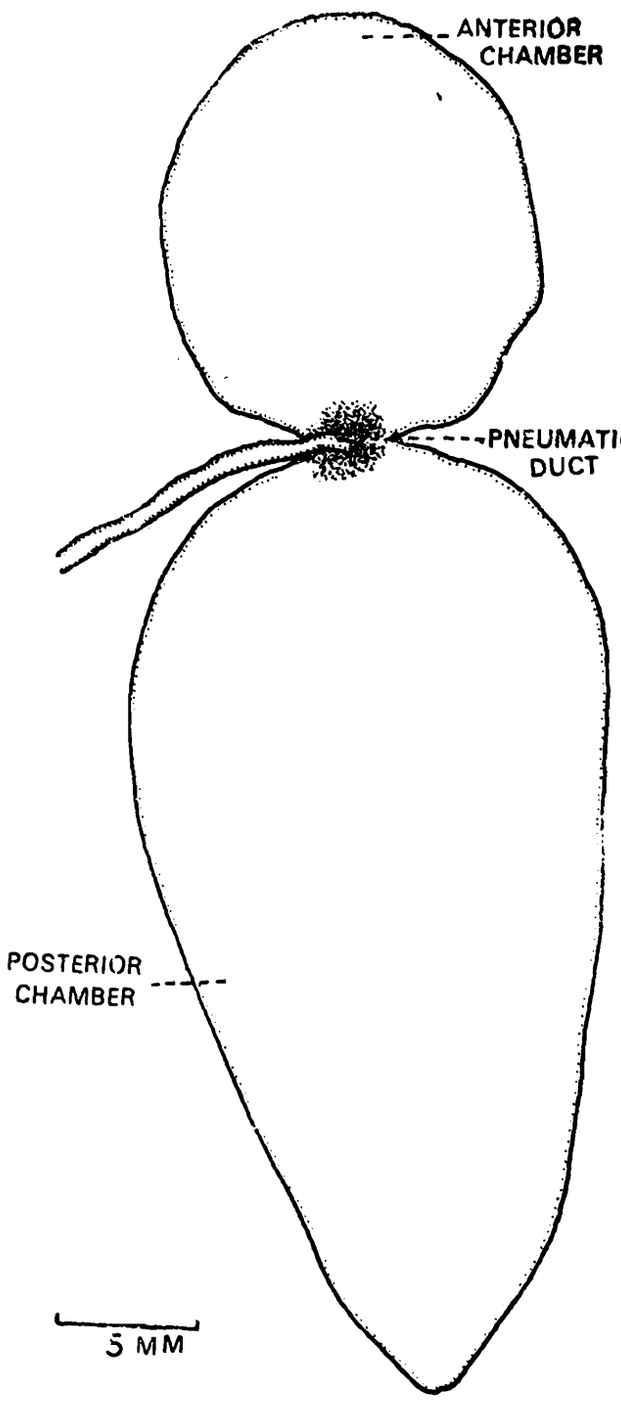


FIG 237

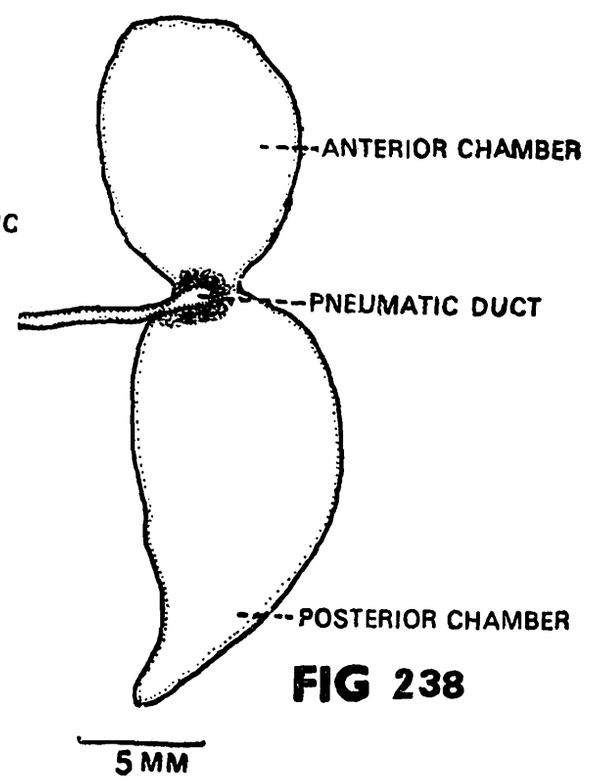


FIG 238

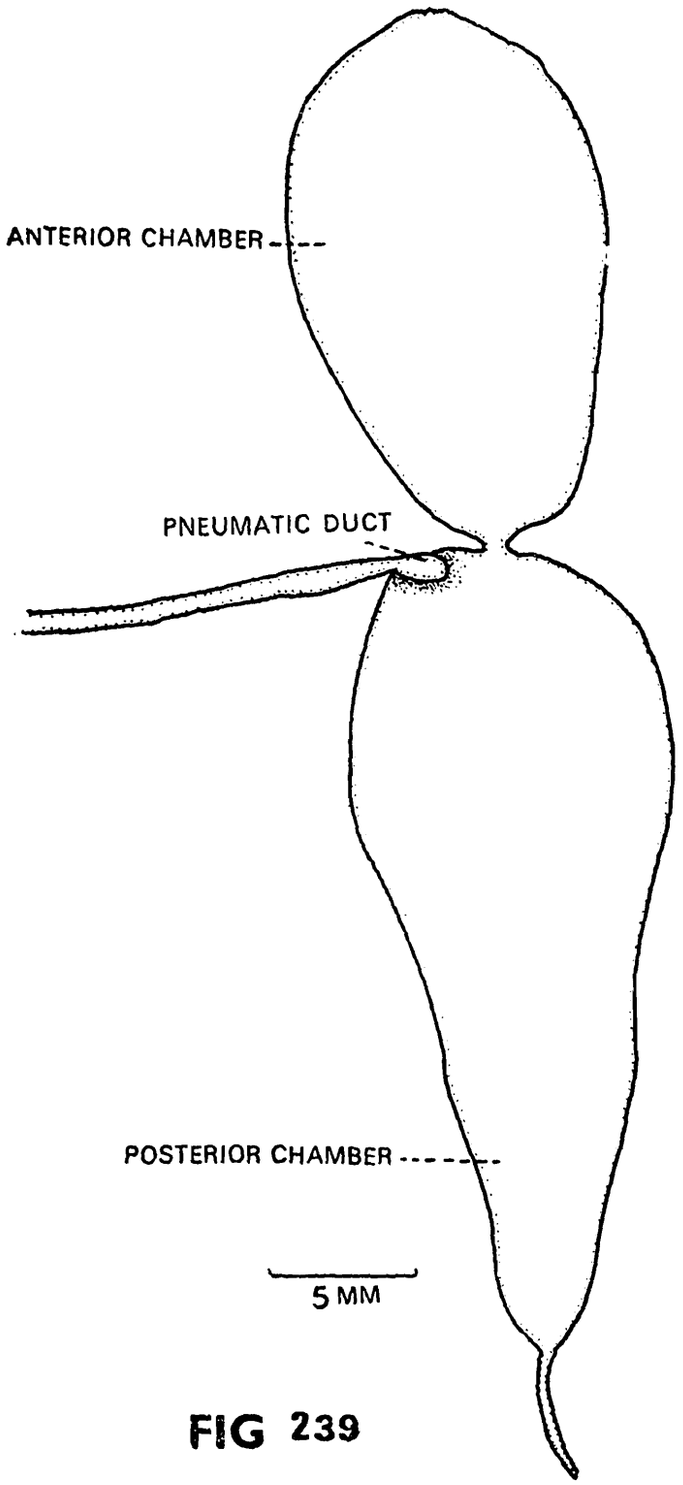


FIG 239

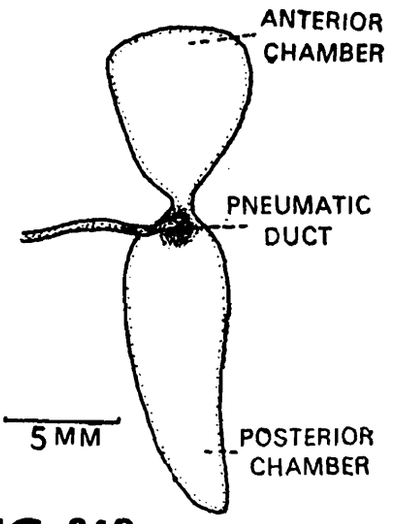


FIG 240

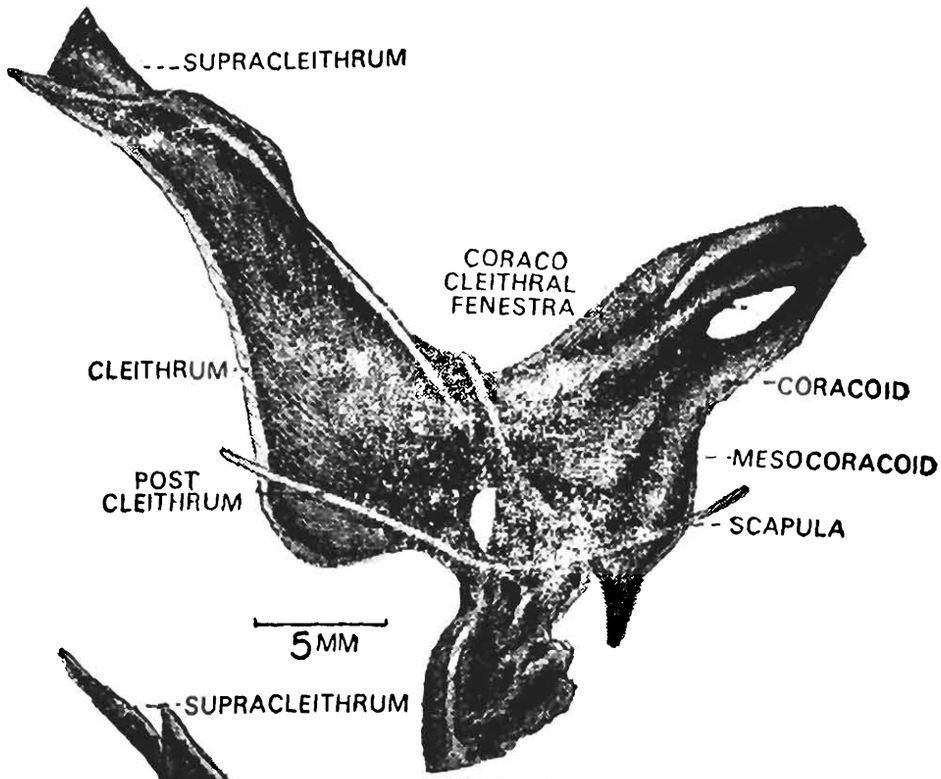


FIG 241

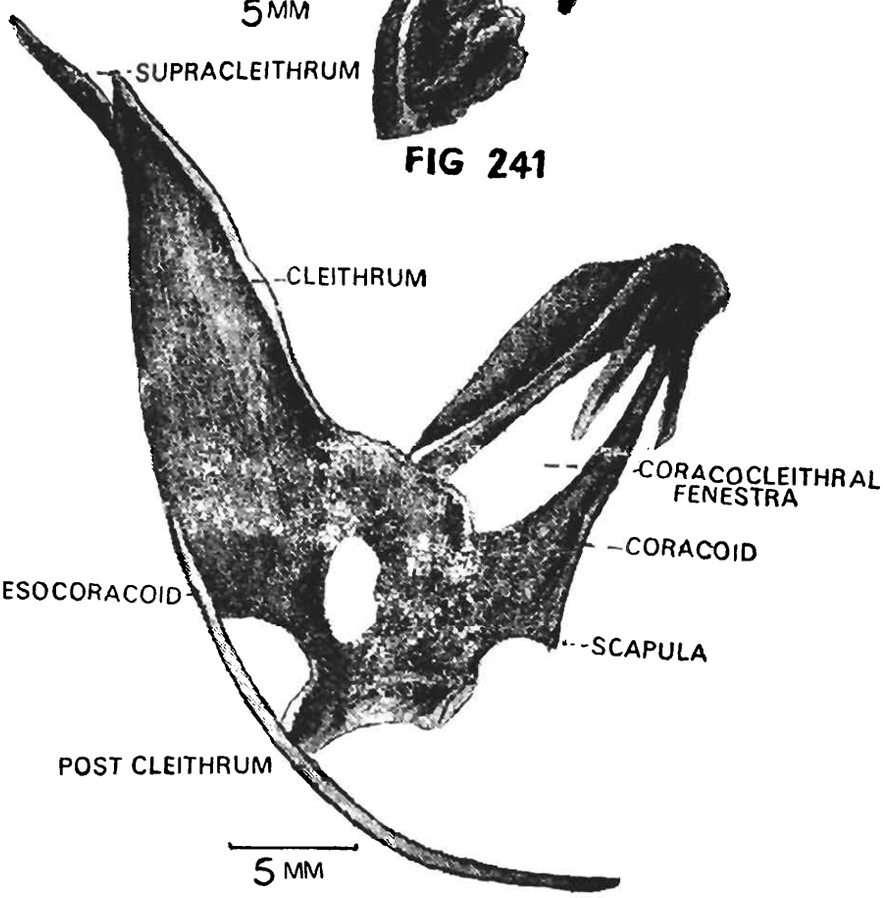


FIG 242

Figs. 241-252. Inner views of left ramus of pectoral girdle of *Schizothorax richardsonii*, *Diptychus maculatus*, *Schizopygopsis stoliczkae*, *Ptycobarbus conirostris* *Schizothoraichthys micropogon*, *S. esocinus*, *S. labiatus*, *Labeo dero*, *Schismatorhynchus nukta*, *Garra lamta*, *Aspidoparia morar* and *Rasbora daniconius* respectively.

Supracleithrum (Figs. 241-252) : It is a small strip of bone which connects the girdle with thc neurocranium and forms the hard bony ridge at the opening of the branchial chamber. It is much developed and elongated in *Schizopygopsis stoliczkae* while thinner and smaller in others.

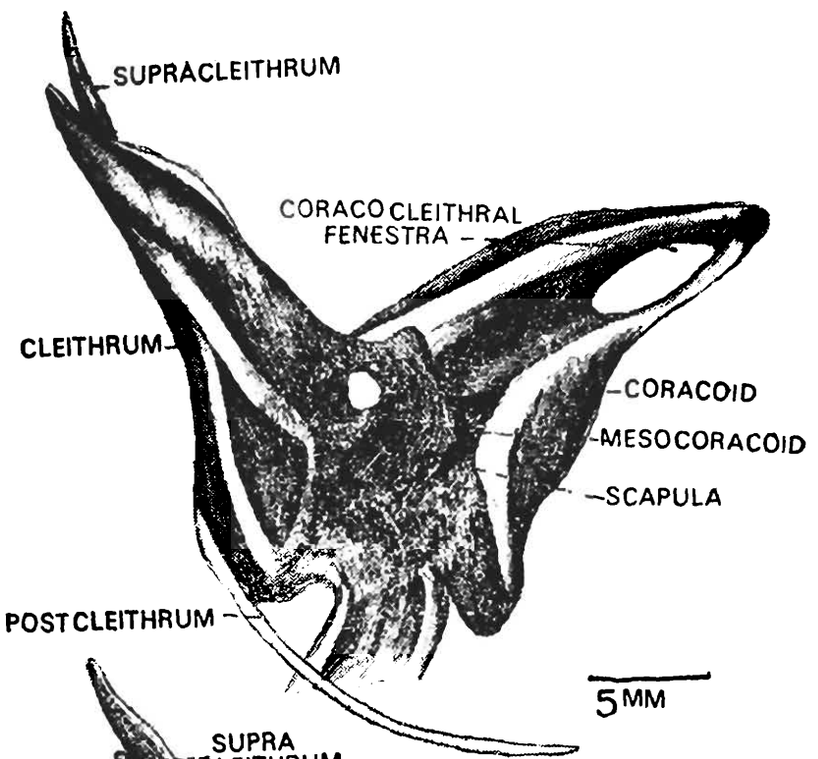


FIG 243

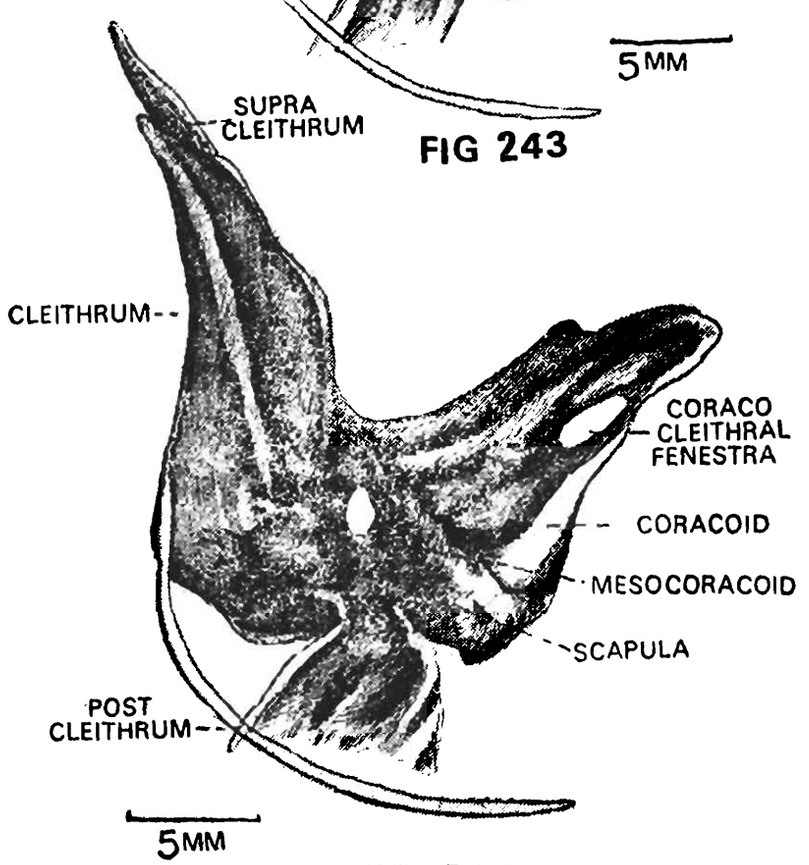


FIG 244

Cleithrum (Figs. 241-252) : It is the largest bone and consists of a vertical limb and a lower medial limb. At the angle of the two limbs,

the cleithrum is much flattened. The medial limb of the cleithrum articulates with the coracoid at the base and at the mesial tip, leaving a coraco-cleithral fenestra, the size of which differs in the species studied.

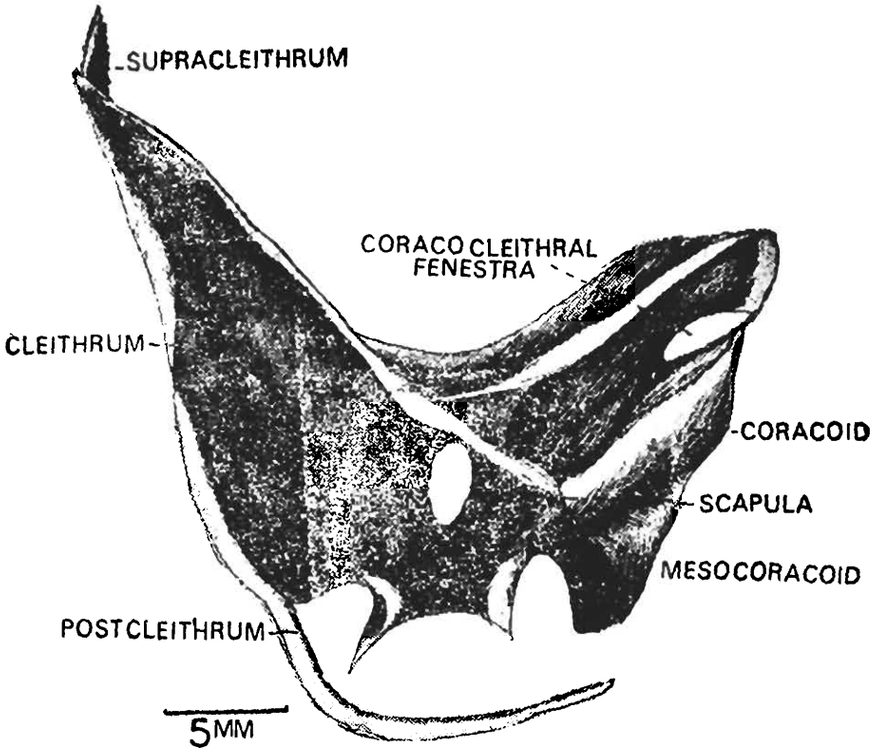


FIG 245

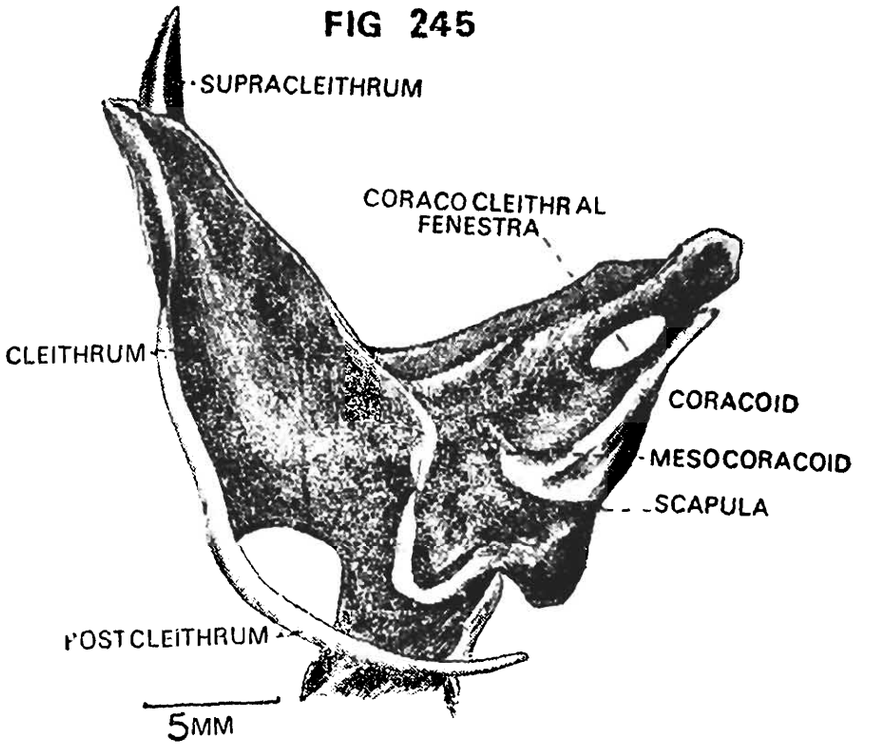


FIG 246

It is large and elongated in *Diptychus maculatus*, *Labeo dero*, *Schismatorhynchus nukta*, *Rasbora daniconius* and *Aspidoparia morar* while the fenestra is much reduced in other species under report.

In all the schizothoracine genera, *Labeo dero* and *Aspidoparia morar*, the cleithrum takes part in the formation of pectoral symphysis. In *Schismatorhynchus nukta*, *Garra lamta* and *Rasbora daniconius*, the inner

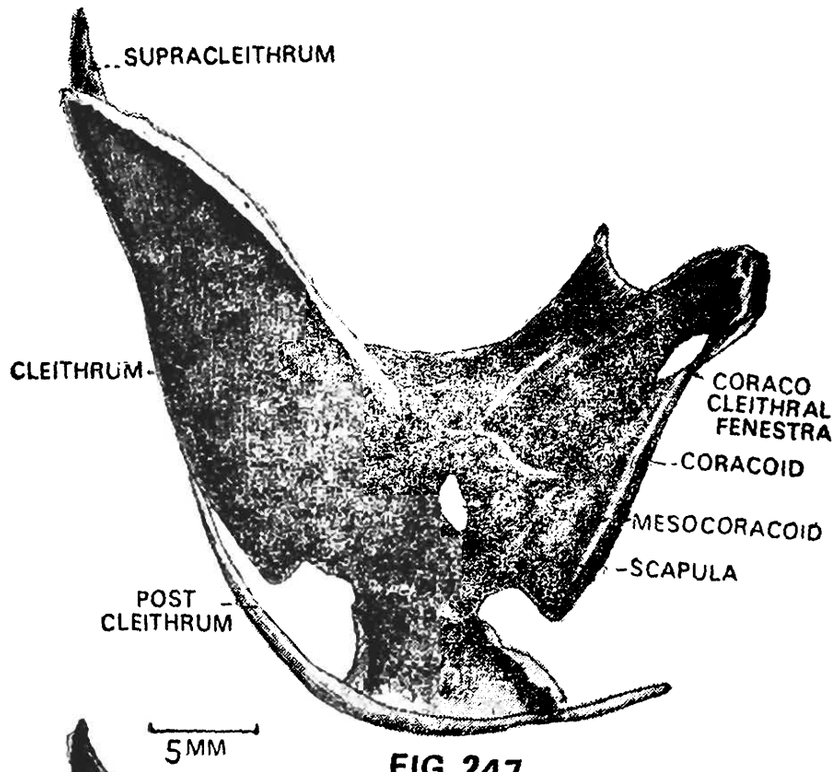


FIG 247

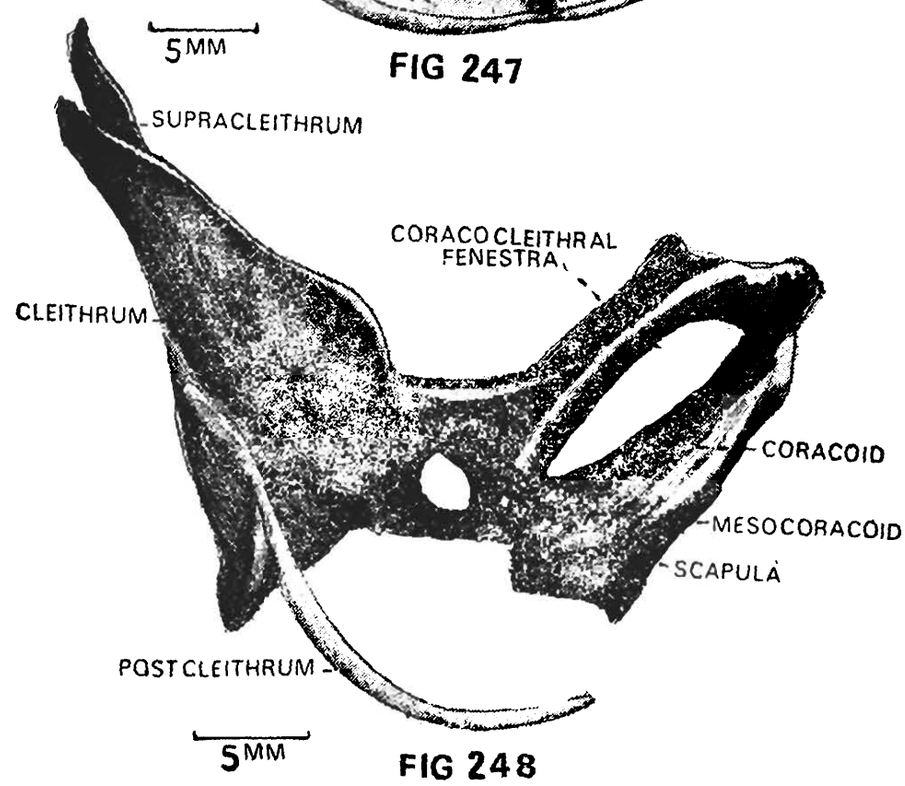


FIG 248

end of the coracoid also takes part in forming the pectoral symphysis. In *Garra lamta*, the medial end of the cleithrum which forms the symphysis is much bigger than those of other species. In *Aspidoparia*

morar, the medial limb of the cleithrum projects vertically downwards so that it forms a sort of oblique keel below each innominate of each pectoral girdle. Such a keel is not observed in any other species under investigation.

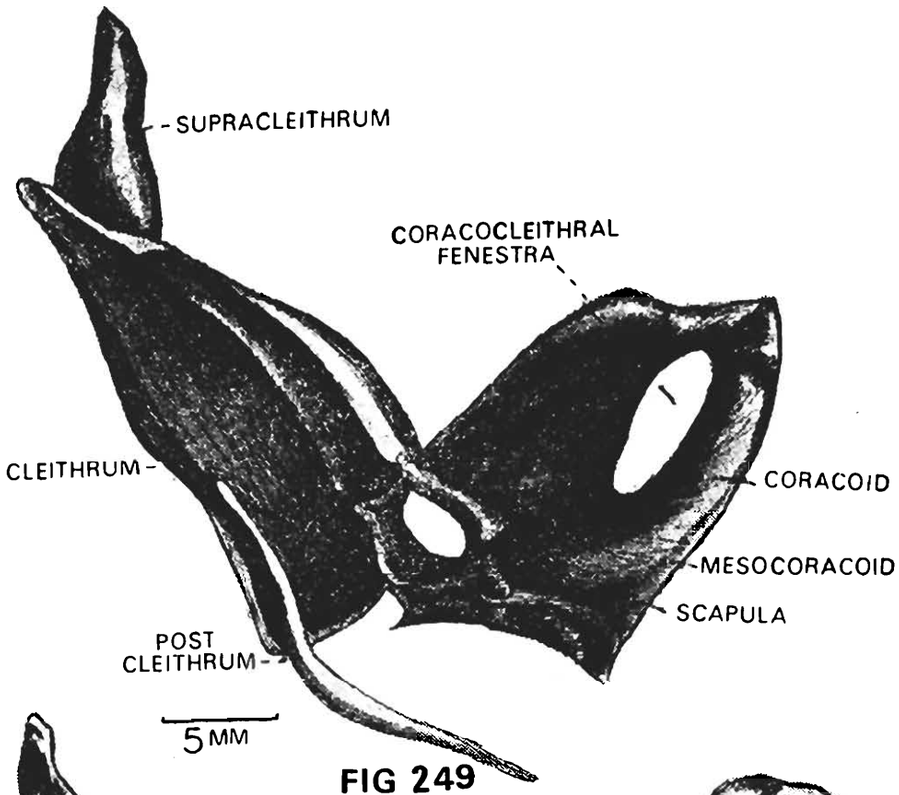


FIG 249

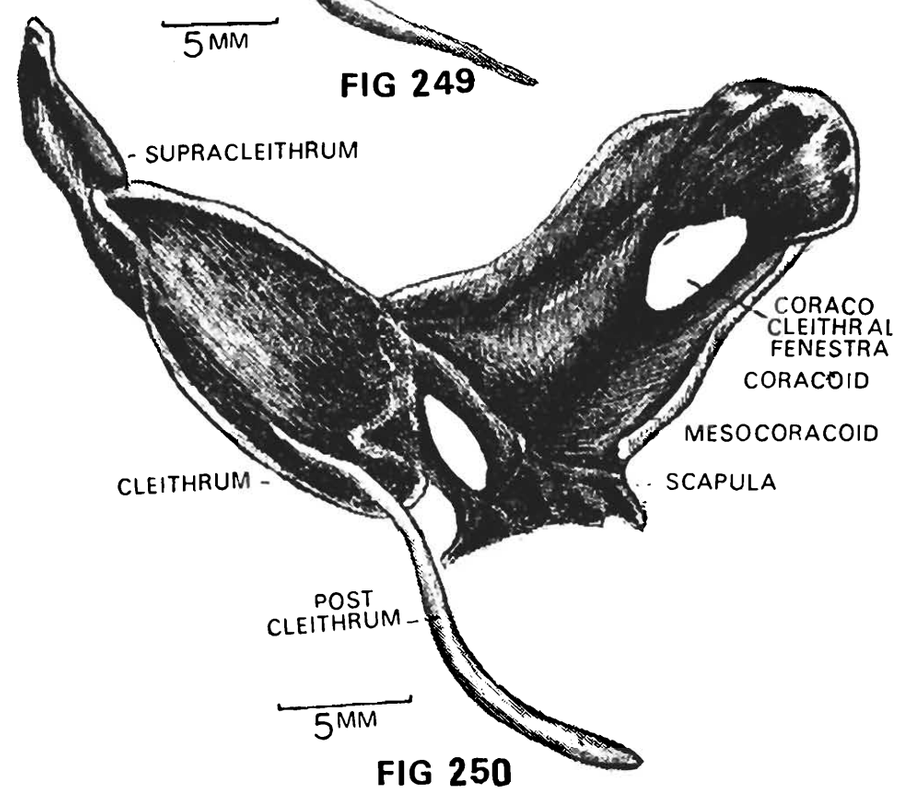


FIG 250

Postcleithrum (Figs. 241-252): Attached on the posterior side of upper limb of cleithrum is a sickle-shaped bent bone-the postcleithrum.

The lower bent portion of the bone runs across the radials and lies embedded in the muscles at the base of pectoral fin. This bone is almost similar in all the species.

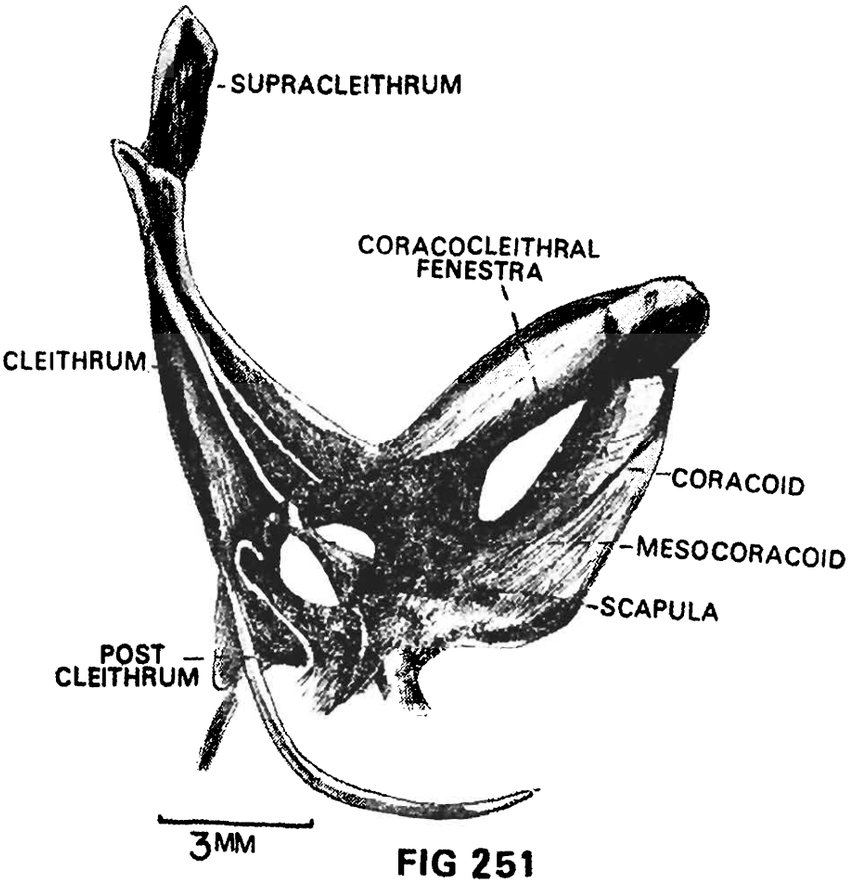


FIG 251

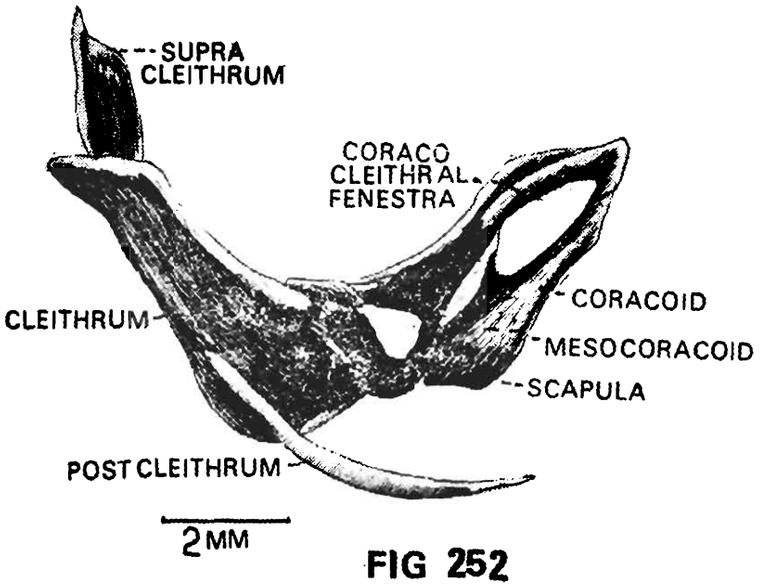


FIG 252

Coracoid (Figs. 241-252) : It is smaller than the cleithrum and is the second largest bone of girdle. Laterally, it articulates with the cleitrum, the scapula and the mesocoracoid. Inner two or three pectoral radials

are attached to the posterior aspect of the coracoid. The mesial end of the coracoid is attached to the posterior aspect of the medial limb of cleithrum. It takes a small part in the formation of pectoral symphysis

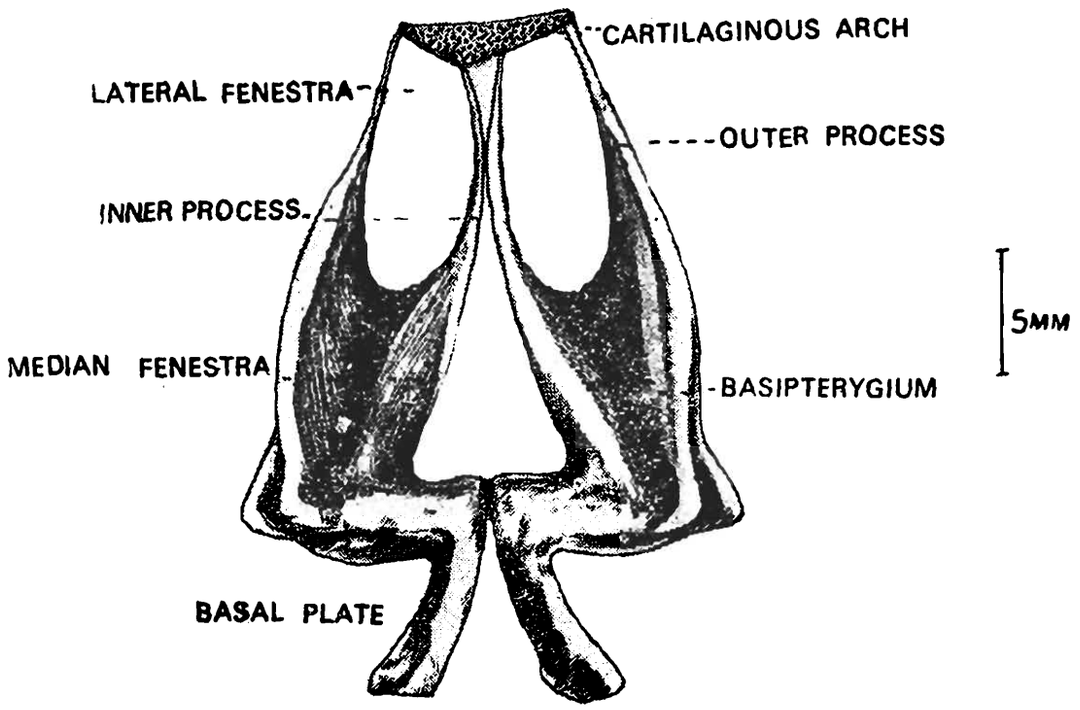


FIG 253

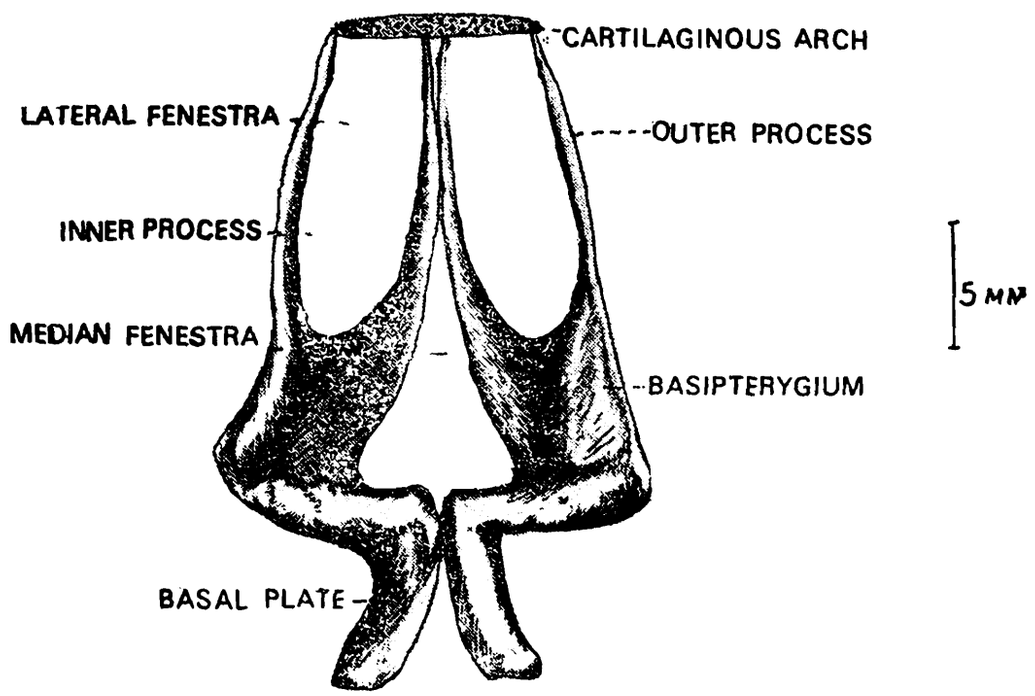


FIG 254

Figs. 253-264. Dorsal aspects of pelvic girdle of *Schizothorax richardsonii*, *Diptychus maculatus*, *Schizopygopsis stoliczkae*, *Ptycobarbus conirostris*, *Schizothoraichthys micropogon*, *S. esocinus*, *S. labiatus*, *Labeo dero*, *Schismatorhynchus nukta*, *Aspidoparia morar*, *Rasbora daniconius* and *Garra lamta* respectively.

in *Schismatorhynchus nukta*, *Garra lamta* and *Rasbora daniconius*, while in rest of the species, it falls short of the pectoral symphysis.

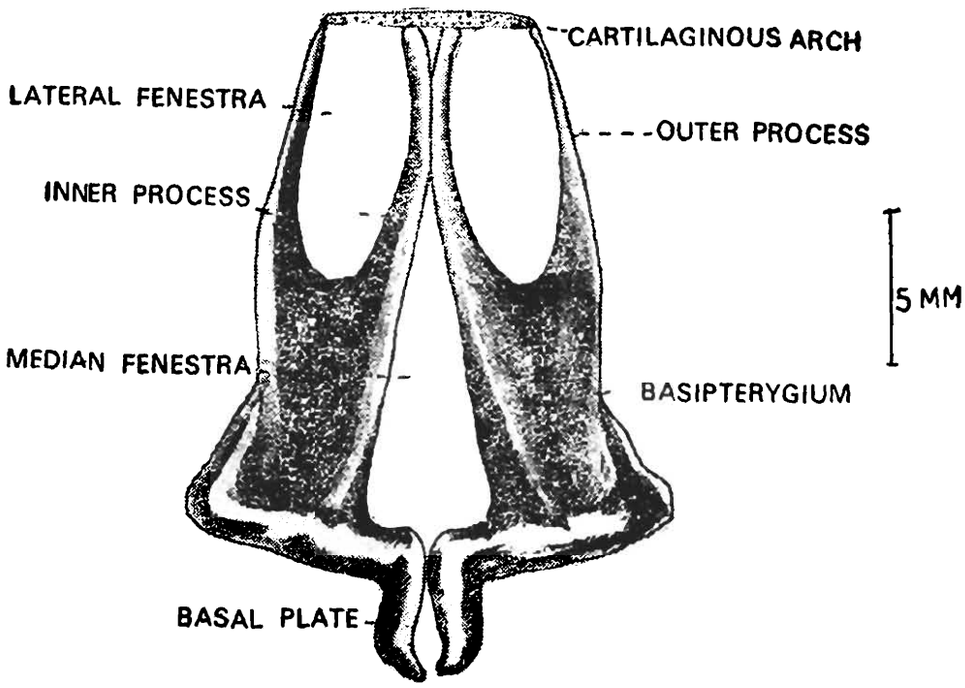


FIG 255

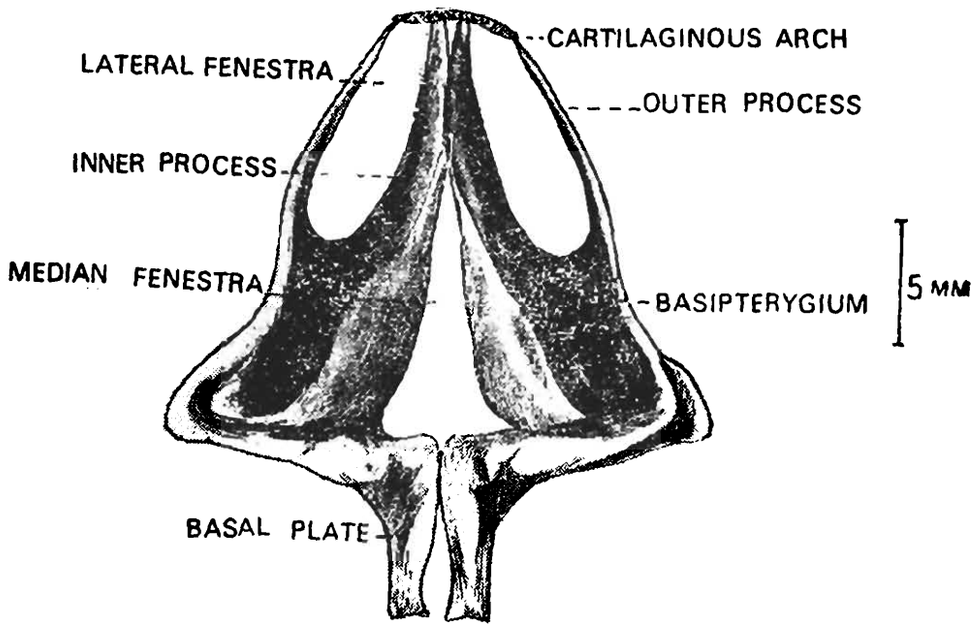


FIG 256

Mesocoracoid (Figs. 241-252) : It is a bent rod of bone whose upper end articulates with the cleithrum and the lower with the coracoid and scapula, thus leaving a fenestra. It is vase shaped in *Schizothorax*

richardsonii Schizothoraichthys spp., *Labeo dero* and *Schismatorhynchus nukta*. It is semilunar in *Schizopygopsis stoliczkae* and 'L'-shaped in *Diptychus maculatus*. In *Garra lamta*, *Rasbora daniconius* and *Aspidoparia morar*, it is reduced to a splint.

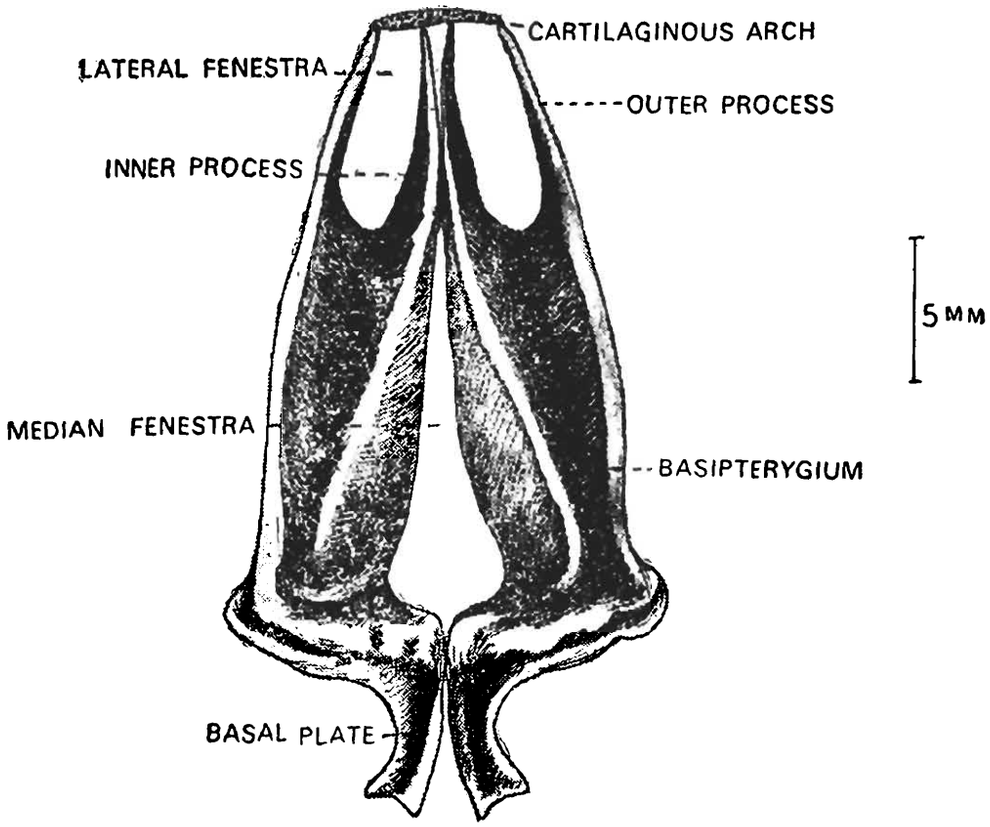


FIG 257

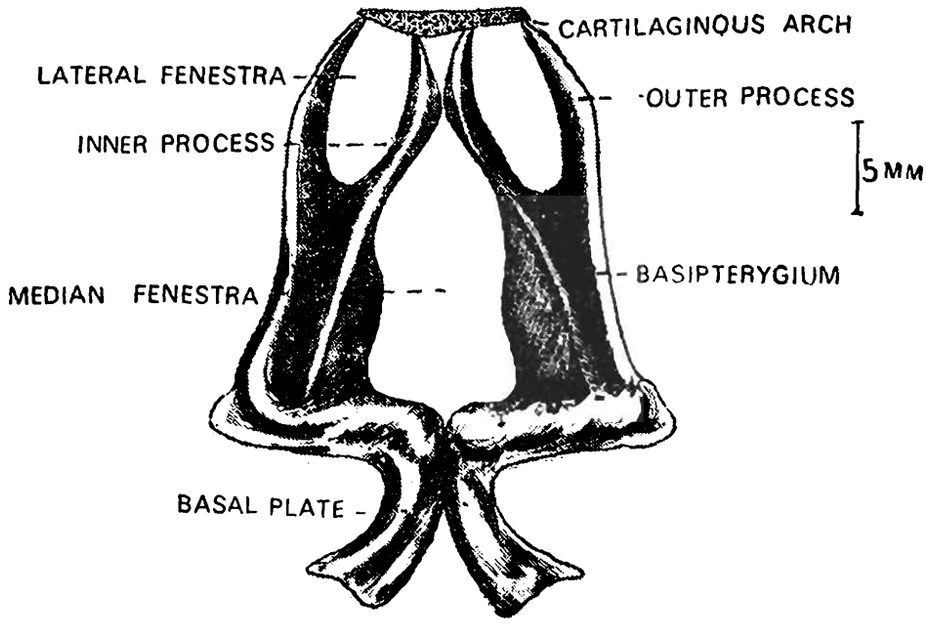


FIG 258

Scapula (Figs. 241-252) : It is a small, curved bone, the two sides of which articulate with the inner side of the cleithrum and the

coracoid, leaving a scapular foramen inbetween them. The foramen is very long in *Aspidoparia morar*. The scapula is attached anteriorly with the cleithrum, dorsoanterioly with the upper end of the mesocoracoid

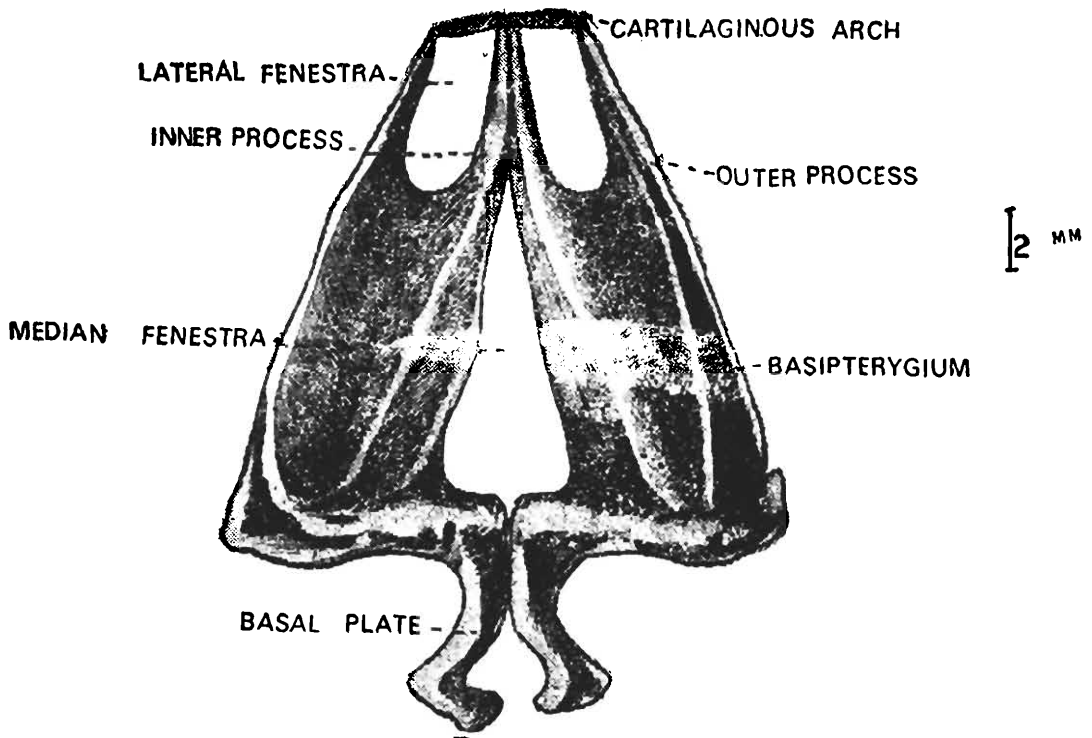


FIG 259

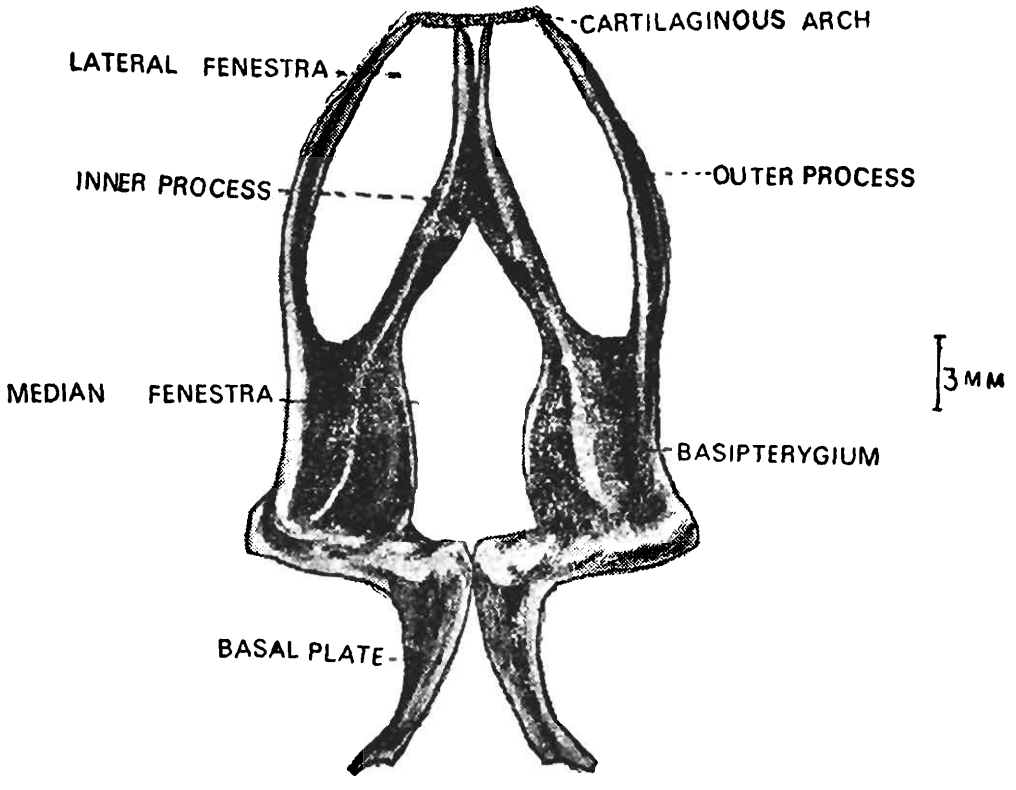


FIG 260

and medially, with the articulating ends of the cleithrum and the coracoid.

Pelvic Girdle :

The pelvic girdle is embedded in the flesh of the abdominal wall and helps to support the pelvic fin. It is connected to the vertebral column through the rib of an abdominal vertebra. The number of

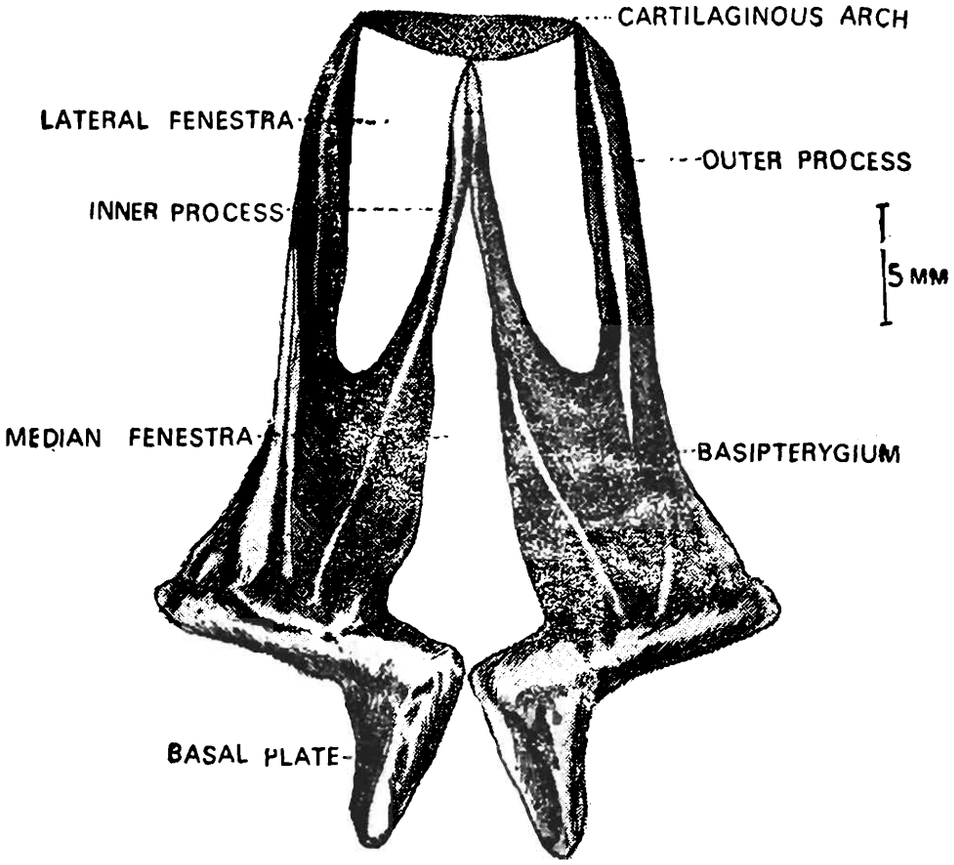


FIG 261

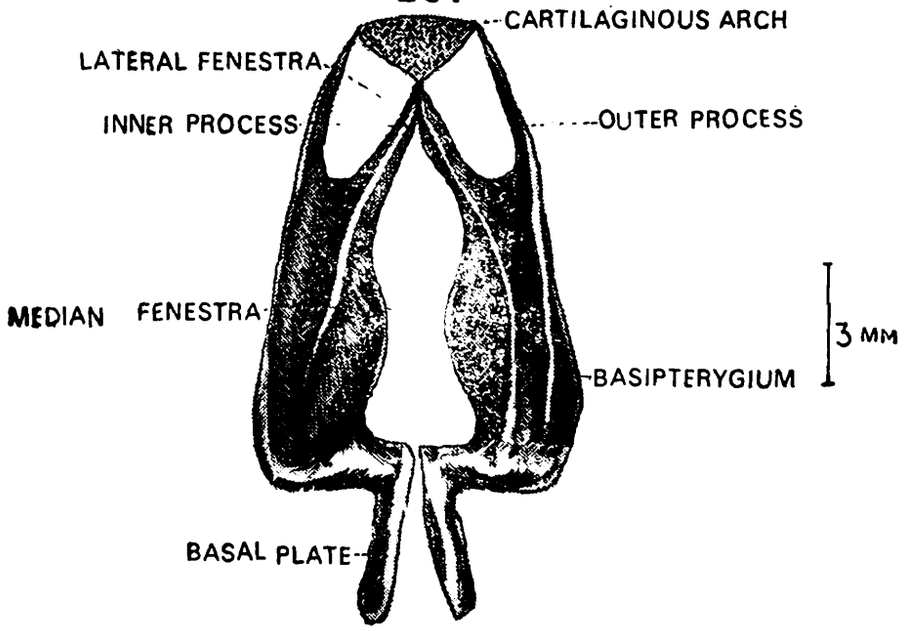


FIG 262

vertebrae whose ribs help to connect the pelvic girdle with the vertebral column differs in different species. The pelvic girdle is

composed of two halves, each formed by an ossified bony plate, the basipterygium.

Basipterygum (Figs. 253-264) : Each basipterygium consists of a plate-like body which gives off anteriorly a pair of anterior processes and posteriorly, a posteromedial process. The anterior process has an

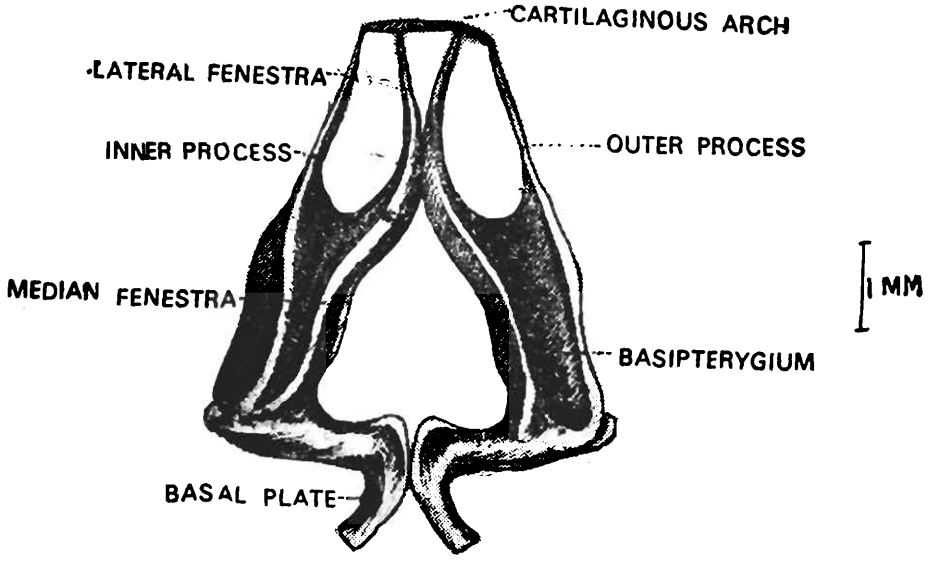


FIG 263

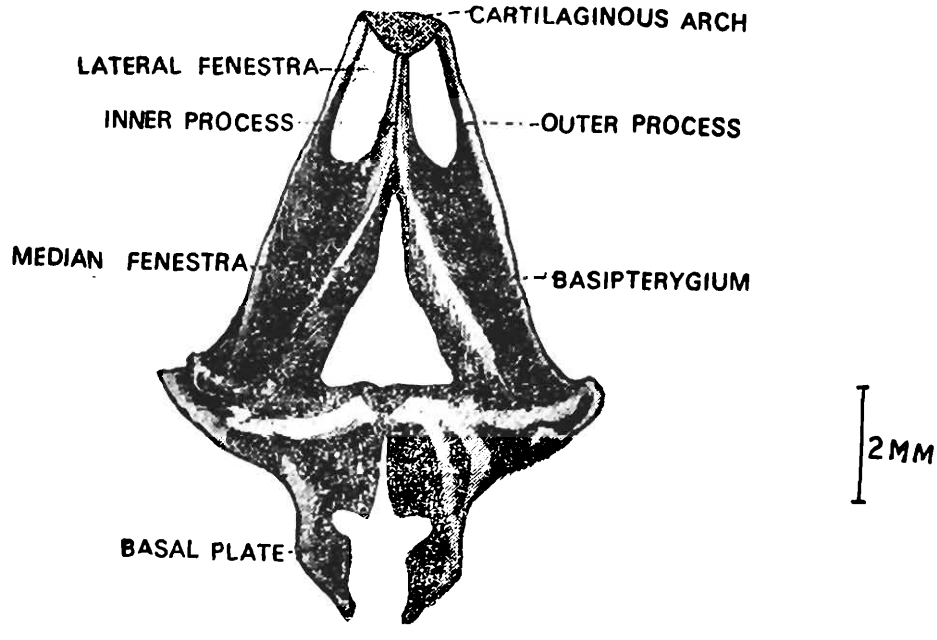


FIG 264

outer and an inner lateral plate. The two plates are united at the tip by a sheath of cartilage, forming a lateral fenestra. The size of which differs in all the species studied and may be interpreted as an adaptation to the hill-stream mode of life.

The depth of the lateral fenestra is less than $\frac{1}{2}$ the total length of basipterygium in *Schizothorax richardsonii*. In *Schizopygopsis stoliczkae*

and *ptycobarbus conirostris*, it is nearly $\frac{1}{2}$ its length whereas in *Schizothoraichthys* spp., neary $\frac{1}{3}$rd the total length of the basipterygium. In *labeo dero*, the depth is $\frac{3}{5}$th while it is slightly less so in *Schismatorhynchus nukta*. In *Garra lamta*, the depth is only $\frac{1}{4}$th the length of the basipterygium. In *Rasbora daniconius* and *Aspidoparia morar*, it is about $\frac{2}{5}$ times while in *Diptychus maculatus*, the lateral fenestra is $\frac{5}{8}$ times deep in total length of basipterygium.

The shape, size and configuration of the anterolateral plates vary in all the genera under report. The inner anterior processes in all the species articulate with one another and enclose a medial fenestra, the extent of which again differs. It is narrow and short in *Schizothorax richardsonii*, *Diptychus maculatus*, *Ptycobarbus conirostris* and *Garra lamta* ; slightly elogated in *Schizopygopsis stoliczkae*, *Schizothoraichthys micropogon* and *Schizothoraichthys labiatus* while it is broad in rest of the species under report. In *Labeo dero*, *Schismatorhynchus nukta* and *Garra lamta*, from the middle of dorsal aspect of the inner lateral processes, a vertical ridge ending anteriorly into a small process, is present.

From the posteromedial side of each basipterygium arises a curved and stout posterior process. It bears thin cartilaginous extensions at its tip. Each of these processes is thinner and pointed at its tip in *Rasbora daniconius* and *Aspidoparia morar* while in rest of the species it is well developed, strong and blunt.

D. **Caudal Skeleton**

(Figs. 265-276)

The caudal fin in all the fishes under investigation is homocercal. But the skeleton supporting the fin, which is formed by the last few vertebrae, does not agree to the external homocercy. The urostyle is turned upwards and a series of seven hypurals are attached along the ventral aspect of the urostyle as well as the centrum of last vertebra. Lying just dorsal to the urostyle, is a small piece of bone named as parhypural. The hypurals are expanded at their tips and along with the urostyle, support the bases of caudal fin rays.

The neural spine of the last centrum is short and sharp. The tip of the neural spine supports one epiural. The urostyle along with the hypurals represents the urohypural complex which supports the caudal fin rays. Above the urohypural complex, the epiurals along with the modified neural spines of the penultimate vertebra support the anterior fin rays of the caudal fin while below the complex similar degenerate fin rays are borne on the modified haemal spines of the

penultimate one. This arrangement of the epiurals, hypurals and the number of elements of the urohypural complex is uniformly similar in all the species, with slight variations in the shape of bones.

There are ten rays in the dorsal lobe of the caudal fin which are borne on the urostyle and four hypurals while in the ventral lobe of the caudal fin, there are nine rays which are supported by the two hypurals and the parhypural. The dorsal and ventral lobes of the fin form a deep notch in the centre, the degree of depth of the notch differs in all the genera and can provide a good index of the speed of the fish.

KEY TO THE SUBFAMILIES AND THE SPECIES

The present study reveals that the osteological characters when taken as such serve as diagnostic features of the subfamilies and species as decribed in the paper. A workable dichotomous taxonomic key is thus, quite helpful in ascertaining the systematic position of tbe subfamilies, the genera and the species.

KEY TO THE IDENTIFICATION :

1. Lateral ethmoid completely covers anterior part of orbit ; supraethmoid notch sharp and narrow or absent ; supraorbital small and does not touch the autosphenotic 2

   Lateral ethmoid covers anterior part of orbit ; supraethmoid notch broad or shallow ; supraorbital large and touches thc autosphenotic .....Subfamily : Rasborinae 11

2. Lateral processes of lateral ethmoid forked ; first basibranchial absent ; urohyal with a broad horizontal wing.....Subfamily : Cyprininae 3

   Lateral processes of lateral ethmoid not forked ; first basibranchial present ; urohyal with a narrow horizontal wing... .....Subfamily : Schizothoracinae 5

3. Supraethmoid notch absent ; preethmoid on anterolateral side of prevomer ; parasphenoid broad anteriorly and narrow in pterosphenoidal region ; parapophysis of fourth vertebra horizontally directed, with posteriorly directed blunt process. ... *Garra lamta.*

Supraethmoid notch present ; preethmoid on posterolateral side of prevomer ; parsphenoid narrow throughout ; parapophysis of fourth vertebra ventrally directed ; posteriorly directed blunt process absent 4

4. Angle of inclination of supraethmid with frontals 30° ; third suborbital nearly twice its width ... *Labeo dero.*

Angle of inclination of supraethmoid with frcntals 85° ; third suborbital nearly as long as broad. ... *Schismatorhynchus nukta*

5. Preehmoid of each side distinguishably paired and easily separable ; supraoccipital spine not extending entire length of supraoccipital ; rostral process of premaxillary well developed ; parapophysis of fourth vertebra posteriorly directed. 6

Preethmoid of each side fused, leaving a faint line of separation ; supraoccipital spine extending entire length of supraoccipital ; rostral process of premaxillary weakly developed or absent ; parapophysis of fourth vertebra ventrally directed. 9

6. Supraethmoid slightly inclined anteriorly ; prevomer hood-shaped anteriorly ; maxillary with a small foramen and its rostral proces directed anteriorly ; pharyngeal teeth in two rows, i.e. 4,3-3,4 ; an anterior process of the fourth parapophysis well marked ... *Ptycobarbus conirostris.*

Supraethmoid and prevomer straight throughout ; maxillary without a formen and its rostral process directed anteromedially ; pharyngeal teeth in three rows, i.e. 5,3,2-2,3,5 ; an anterior process of the fourth parapophysis absent *Schizothoraichthys* 7

7. Parasphenoid broad and interorbital septum much reduced ; optic foramen partly visible ventrally ... *Schizothoraichthys esocinus*

Parasphenoid narrow and interorbital septum well developed ; optic foramen visible ventrally ... 8

8. Epiotic crest with a posteriorly directed spine ; parasphenoid covering small part of prevomer anteriorly ; orbitosphenoid not taking part in formation of optic foramen ... *Schizothoraichthys labiatus.*

	Epiotic crest without any posteriorly directed spine ; parasphenoid covering a large part of prevomer anteriorly ; anterior ⅓rd part of optic foramen formed by orbitosphenoid. ...	*Schizothoraichthys micropogon.*
9.	Prevomer uniformly broad ; opisthotic prsent ; pharyngeal teeth in three rows, i.e. 5, 3, 2-2, 3, 5. ...	*Schizolhorax richardsonii.*
	Prevomer narrow posteriorly ; opisthotic absent ; pharyngeal teeth in two rows, i.e. 4, 3-3, 4.	10
10.	Posterior border of supraoccipital almost reaches foramen magnum ; coracocleithral fenestra large ; biprong hook of the tripus prsent ...	*Diptychus maculatus.*
	Posterior border of supraoccipital falls much short of foramen magnum ; coracocleithral fenestra small ; biprong hook of tripus absent	*Schizopygopsis stoliczkae.*
11.	Supraethmoid notch saucer-shaped, ⅔th deep ; pharyngeal process pointed ; sutural line of demarcation on the bones of dorsal surface of skull not prominent. ...	*Rasbora daniconius.*
	Supraethmoid notch shallow, ½ deep ; pharyngeal process broad, wing-like ; sutural line of demarcation on the bones of dorsal surface of skull promient. ...	*Aspidoparia morar*

DISCUSSION

A few members of the family Cyprinidae inhabit the torrential waters of the high altitudes or the base of the hills. Hora (1927) remarked that there is a significant change in the external morphology of hill-stream fishes and these modifications are acquired as a result of adaptation to a particular type of habitat. It is generally beleived that search for food forced the fishes of the low altitude to enter into swift currents of hill-streams where the absence of enemies, lack of serious competition and the ability to withstand the force of current enabled them to take advantage of the new environment.

The torrential streams of the hills and mountains drainges provide an unusual environment which offers unlimited gradations to aquatic life. The main ecological factors which have greatly influenced the fauna : the strength of the current, abundance of dissolved oxygen and the nature of the food. According to their availability, Hora (1930) divided the hill-stream fishes into different categories. Thus the fishes under report can be described under the following two heads :

(i) Free swimming fishes found in deep pools and main streams.	Large free swimming fishes belonging to genera, *Diptychus*, *Ptycobarbus*, *Labeo*, *Schismatorhynchus* and *Schizothoraichthys*. These fishes are found in swift currents and are capable of porgressing well against the current. Some of them show modifications of the lips which are believed to be used for adhesion to rock surfaces while feeding.
(ii) Fishes living on rocks or amongst the pebbles etc.	Fishes living at bottom on the exposed surface of rocks or amongst pebbles and under side of rocks. In them, the ventral sucker is highly modified for adhesion to the substrate e. g. *Garra*.

Correlated with the external morphological adaptations it has been observed that the osteocranium, the Weberian apparatus and the girdles also show variations which owe a lot to the environmental conditions of these fishes. These variations are described under separate heads.

1. *NEUROCRANIUM*

I. Olfactory Region :

Supraethmoid : The present study reveals that antero-median notch of the supraethmoid is developed to a varying degree of development in the cyprinids. This suggests that the supraethmoid was composed of a pair of bones in extinct cyprinids, the two having indistinguishably fused in the present day forms, a view also supported by de Beer (1937) and Harrington (1955). The presence of a broad and deep notch in column dwellers, viz. *Rasbora daniconius* and a shallow notch in *Aspidoparia morar* is suggestive of their primitive nature. The transitory stage of the fusion of two bones is represented by a narrow and short notch in schizothoraine and two cyprinine genera, i. e. *Labeo dero* and *Schismatorhynchus nukta*. The most advanced stage is the absence of the notch as in *Garra lamta*, a bottom feeder.

In hill-stream fishes, snout is straight in column feeding species while inclined in the bottom feeders. The inclined snout affords least resistance to the surface water currents. In line with the angle of the snout, the supraethmoid has also undergone modifications. In the bottom feeding forms like *Schizothorax richardsonii*, *Diptychus maculatus*, *Schizopygopsis stoliczkae* and *Ptycobarbus conirostris*, this bone is slightly

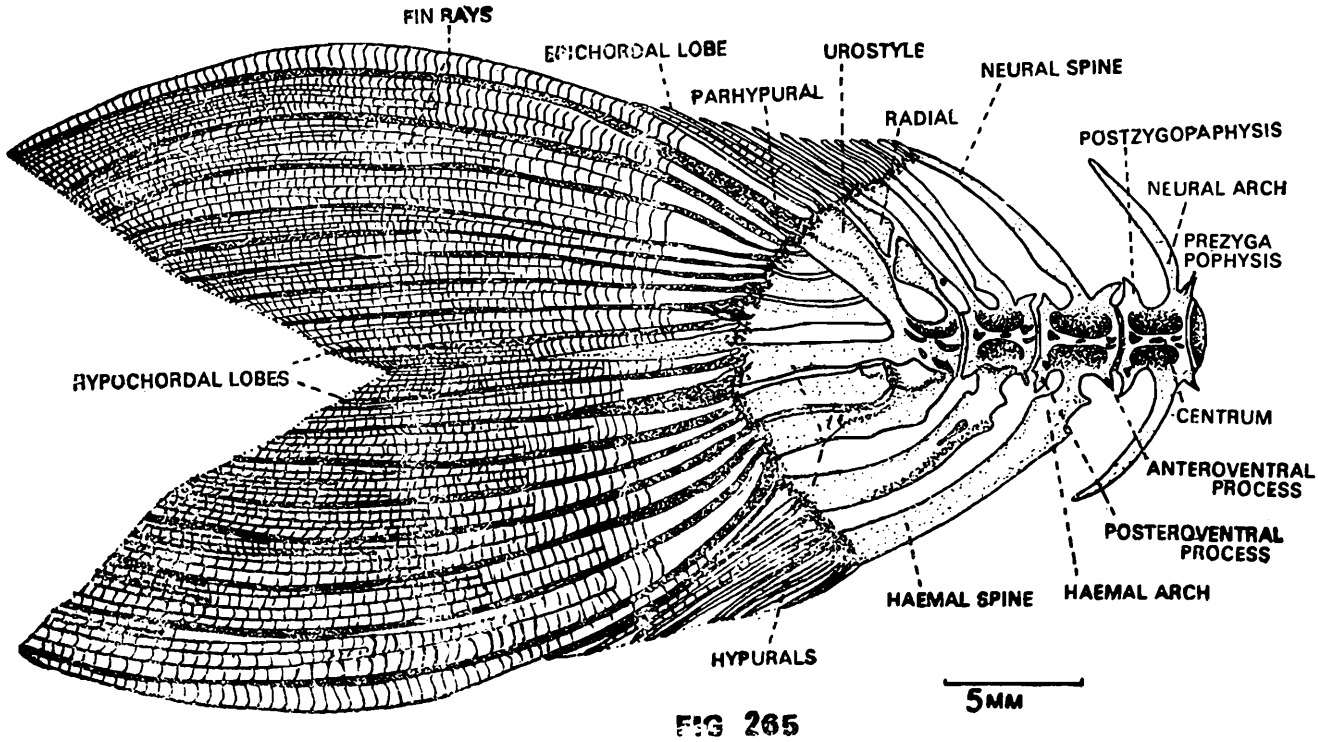


FIG 265

Figs. 265-276. Caudal fins and a few vertebrae of *Schizothorax richardsonii*, *Diptychus maculatus*, *Schizopygopsis stoliczkae*, *Ptycobarbus conirostris*, *Schizothoraichthys micropogon*, *S. esocinus S. labiatus*, *Labeo dero*, *Garra lamta*, *Aspidoparia morar*, *Rasbora daniconius* and *Schismatorhynchus nukta* respectively.

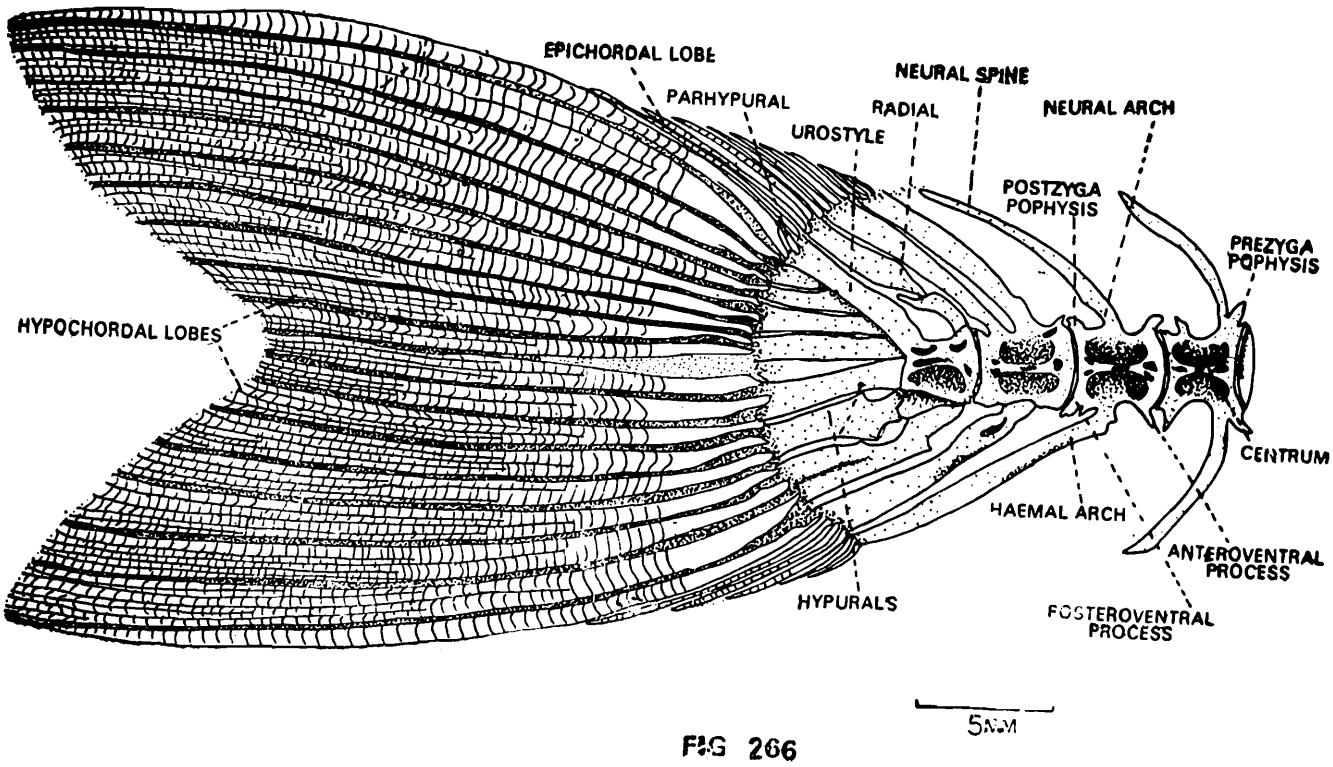


FIG 266

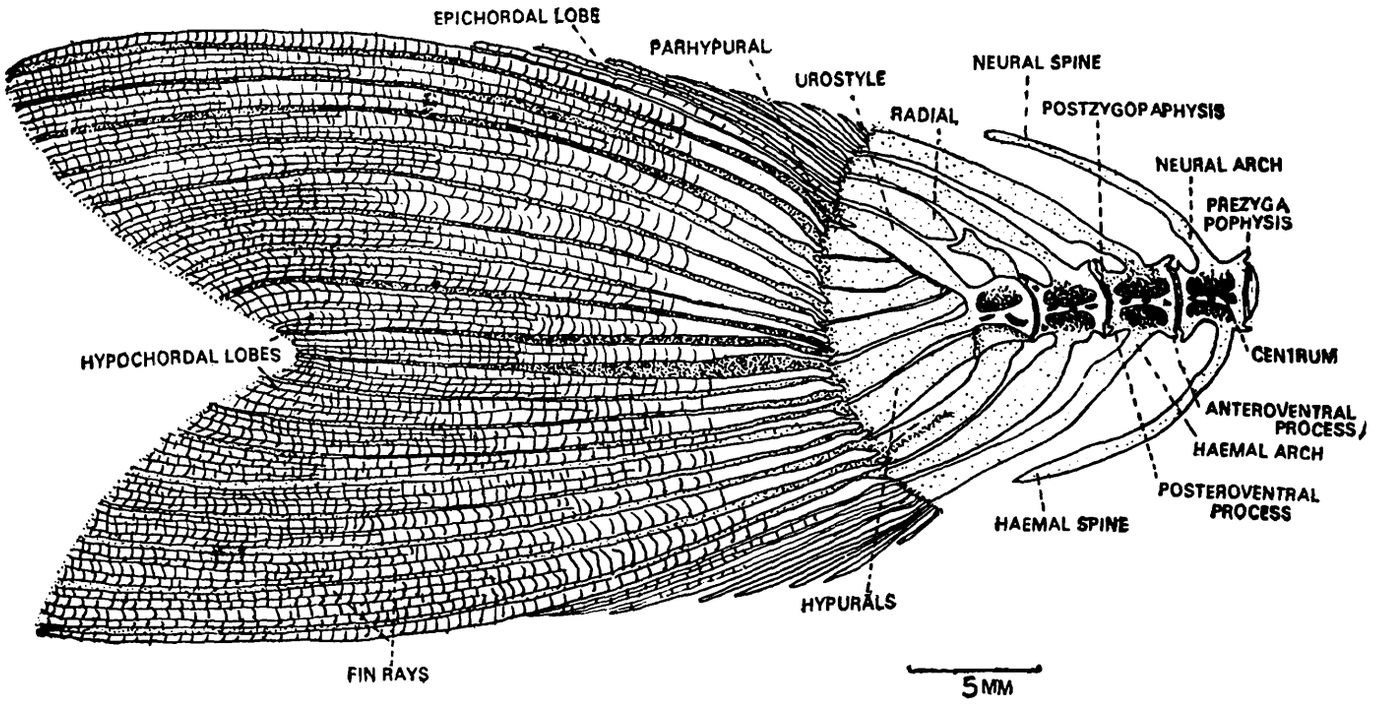


FIG 267

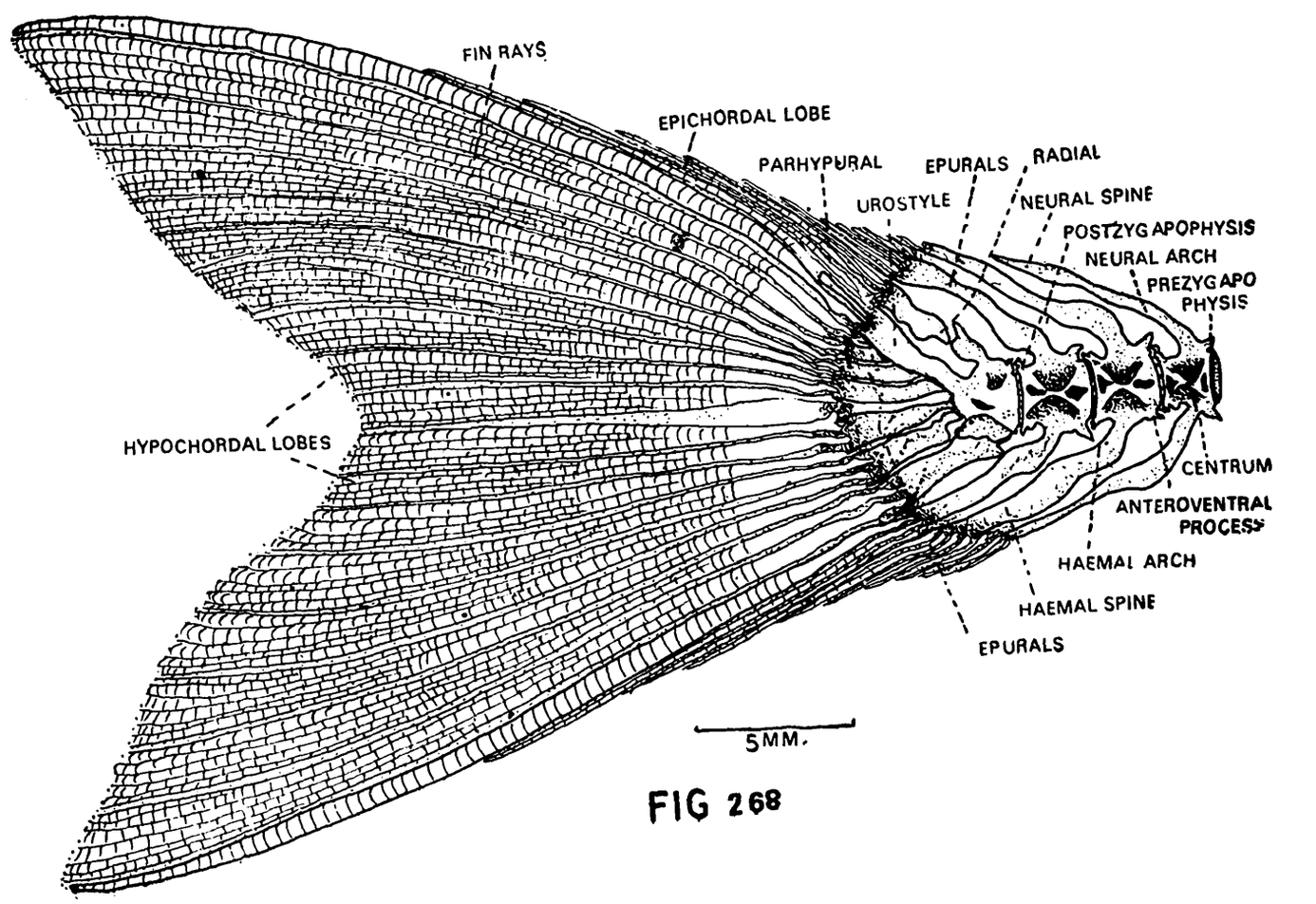


FIG 268

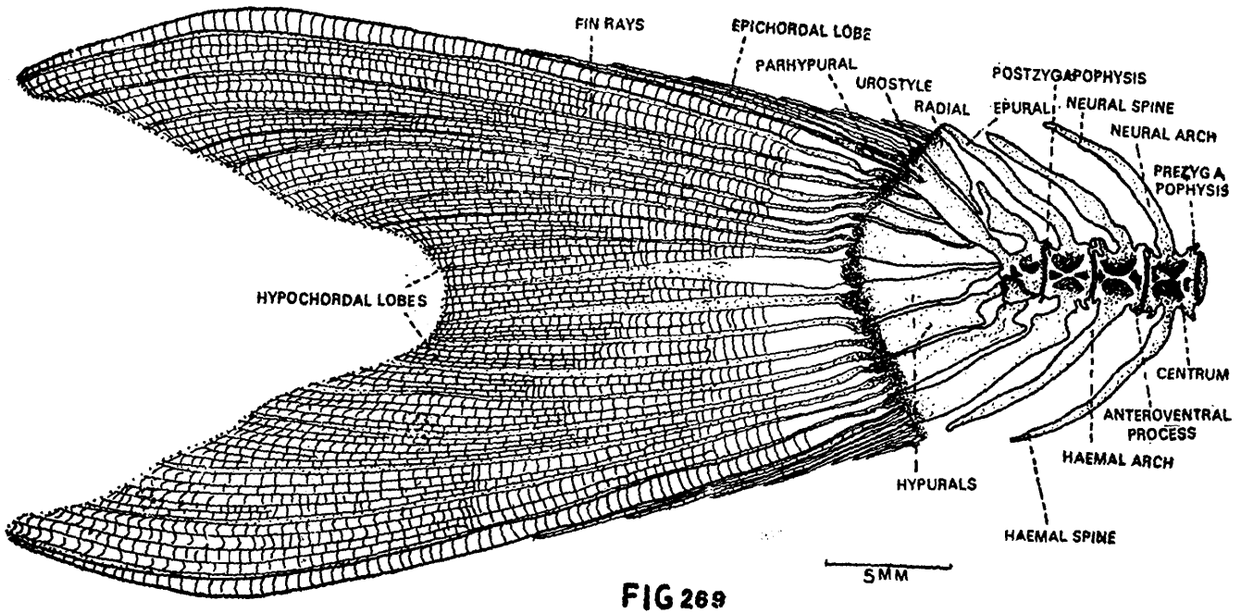


FIG 269

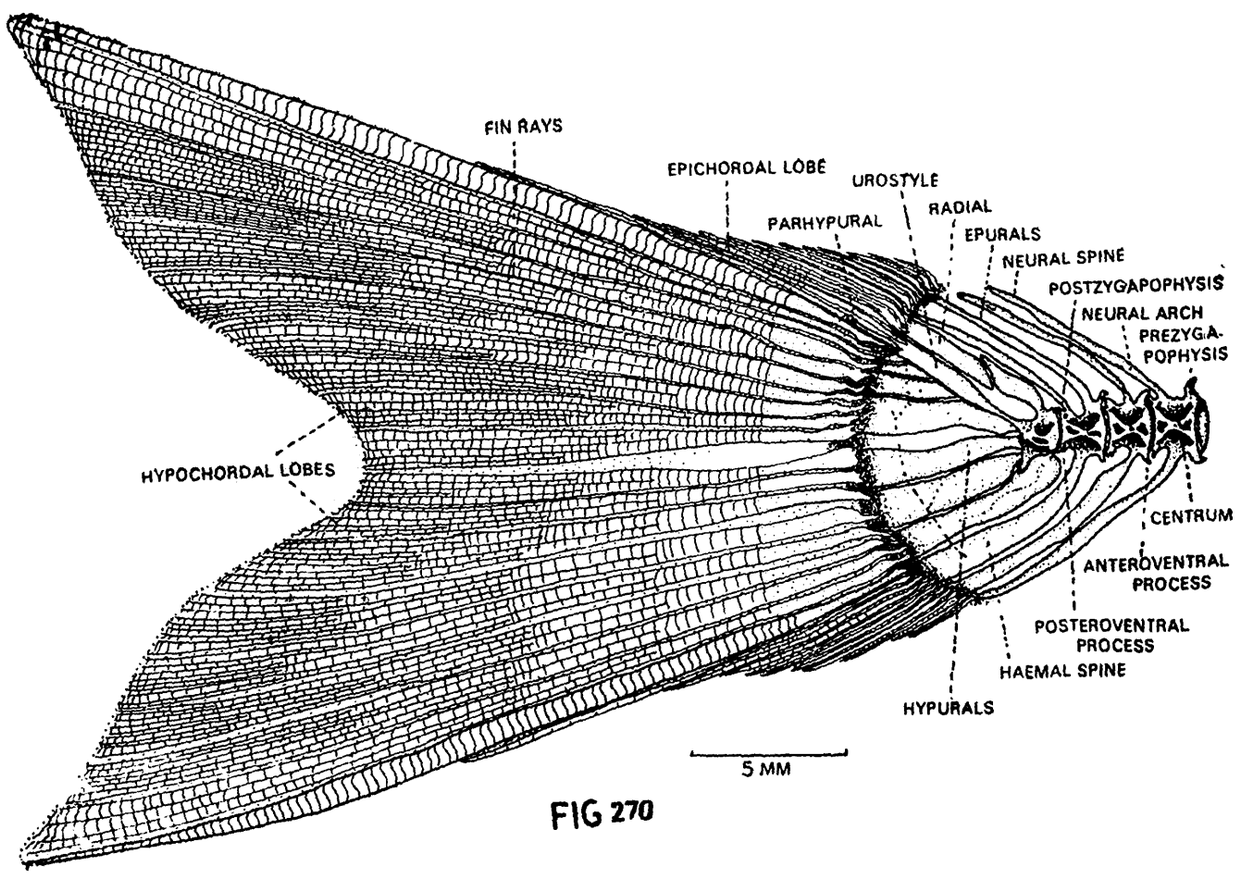


FIG 270

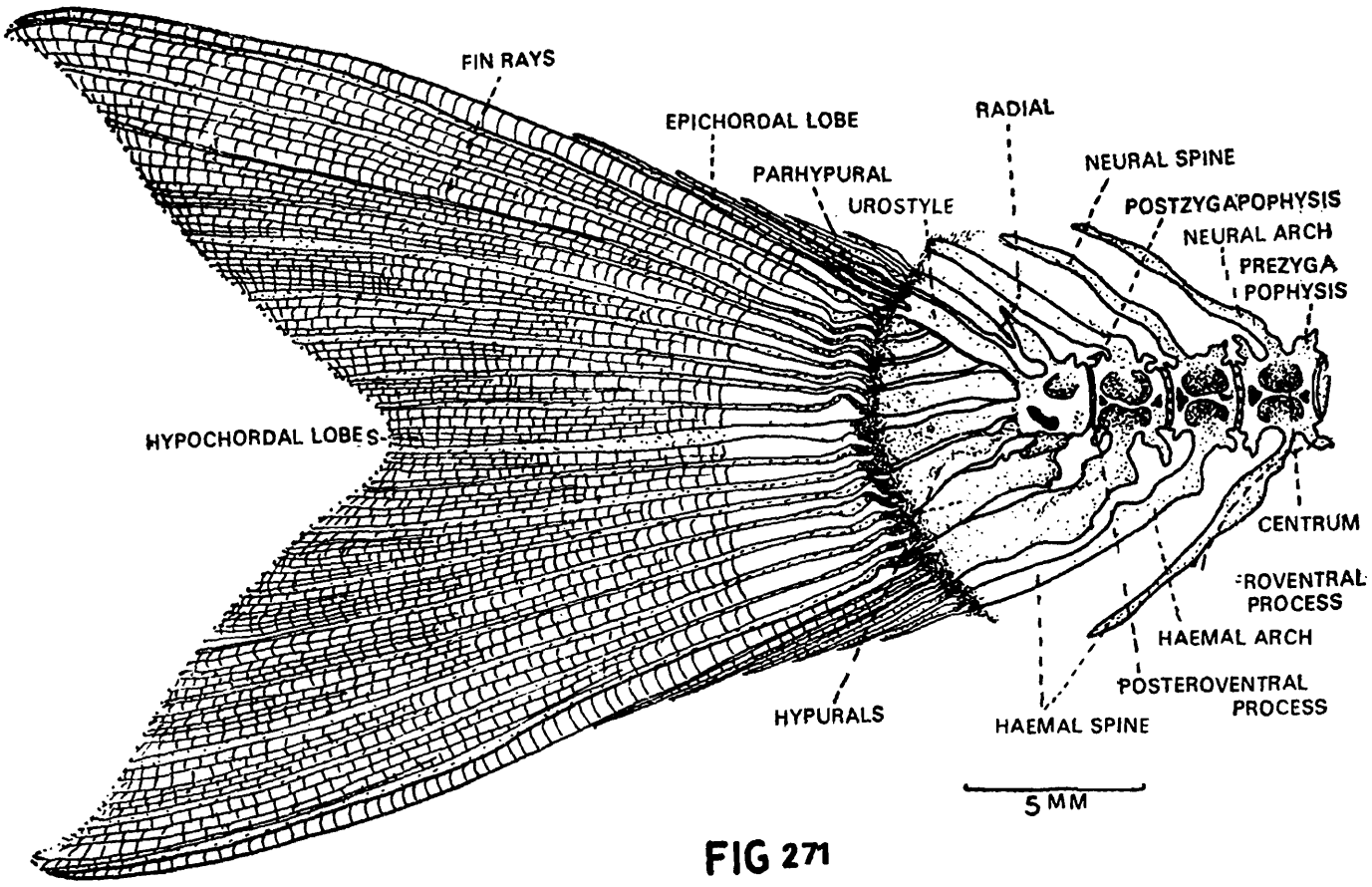


FIG 271

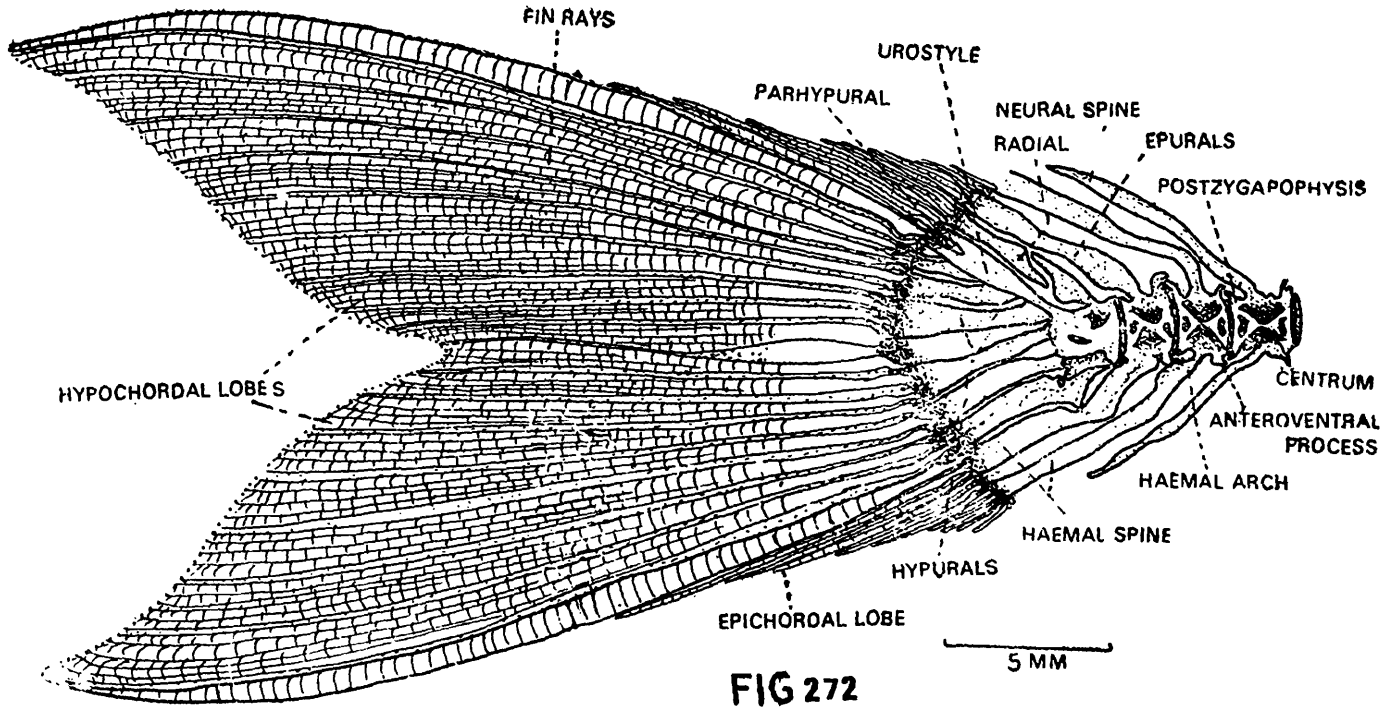


FIG 272

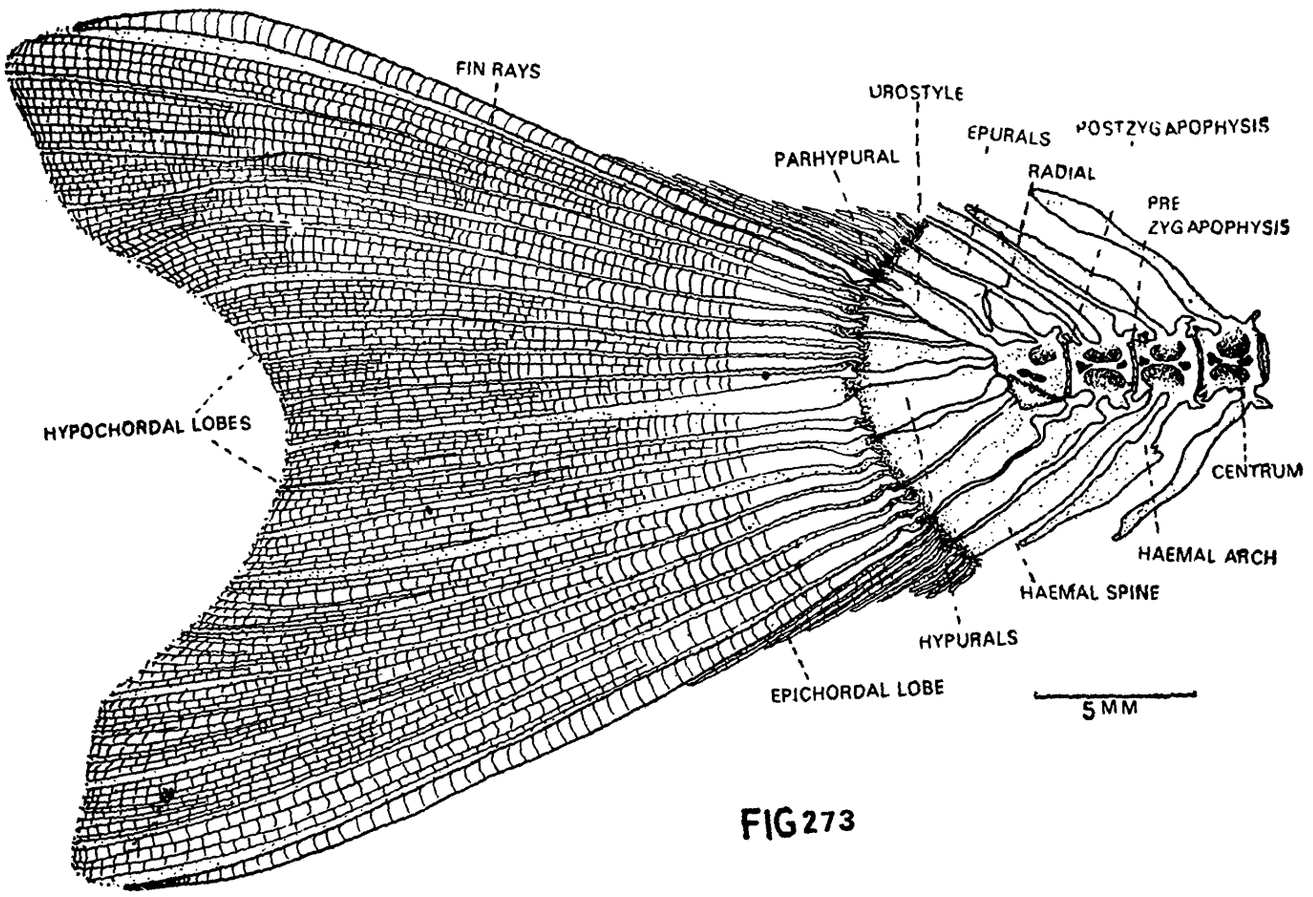


FIG 273

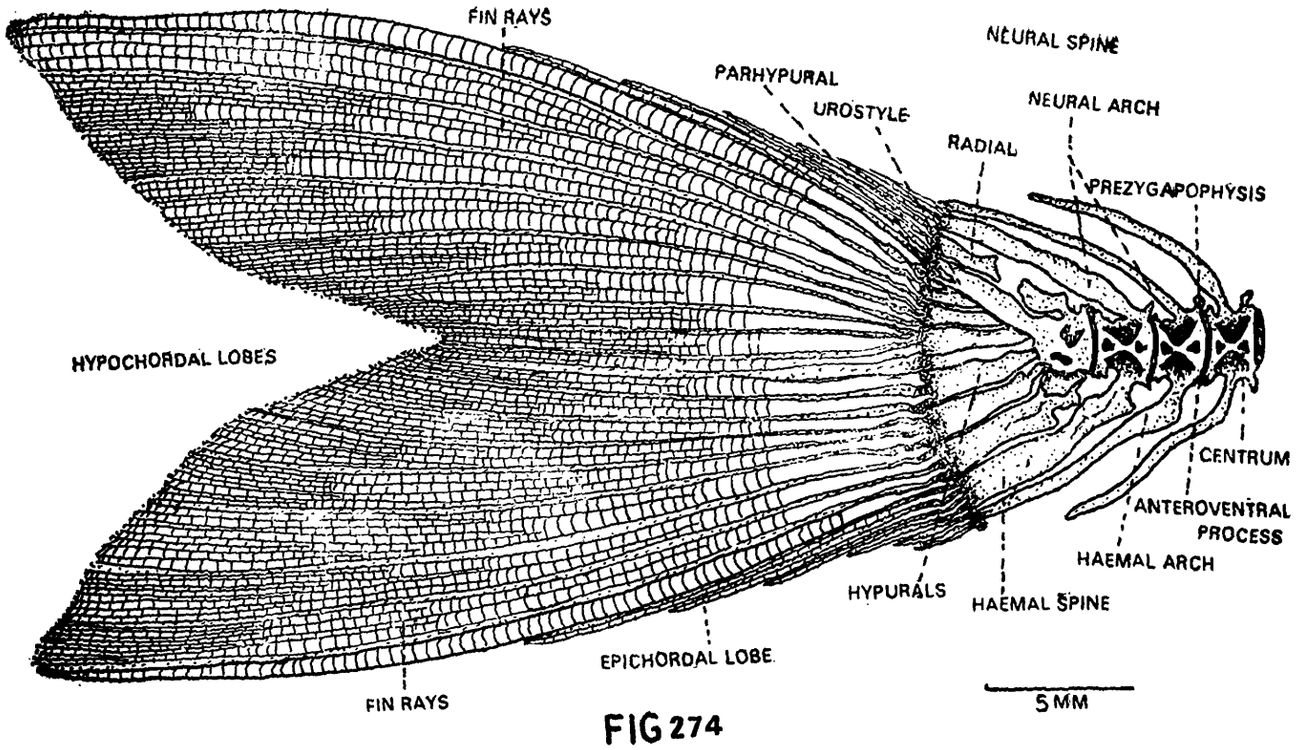


FIG 274

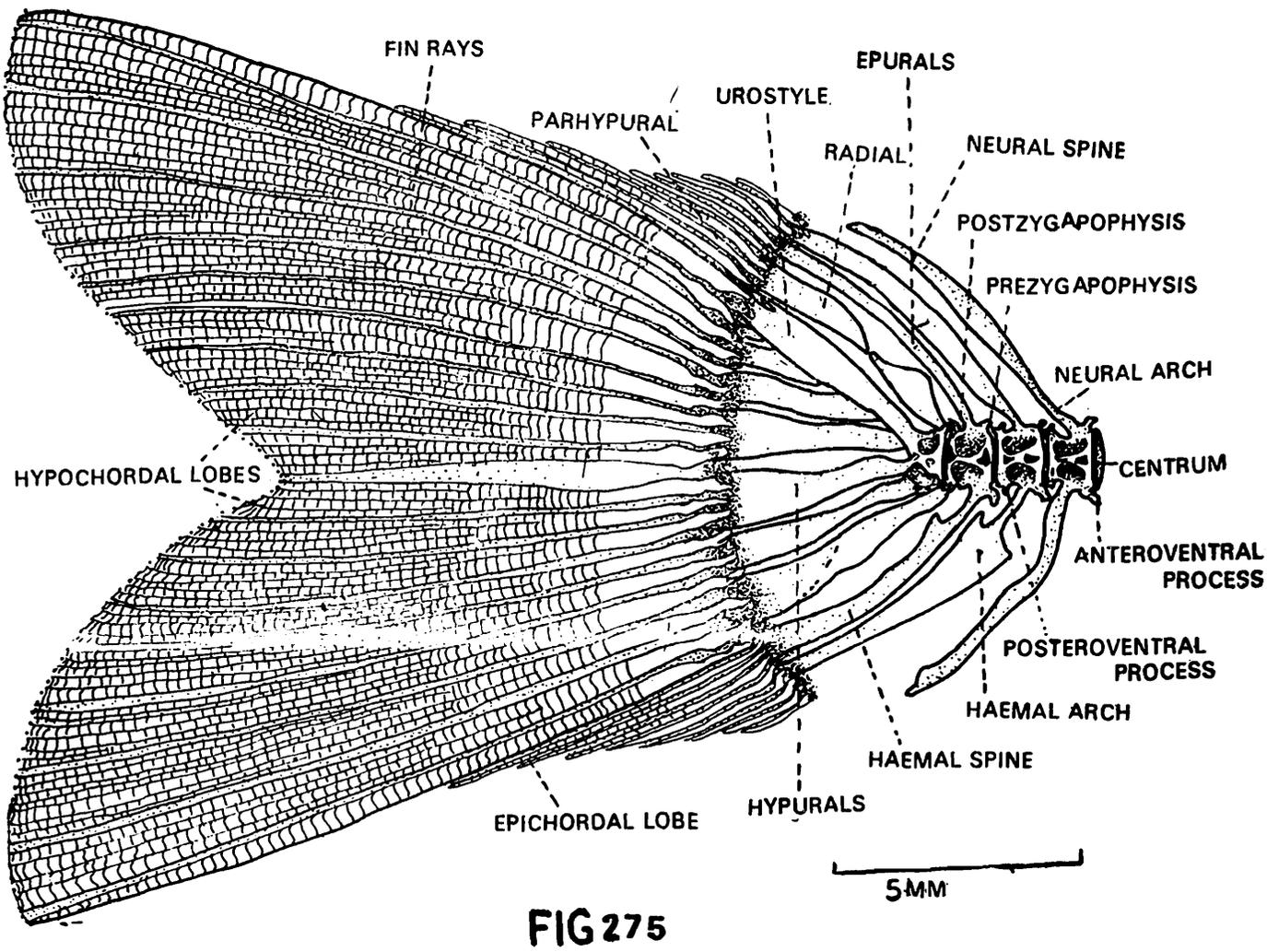


FIG 275

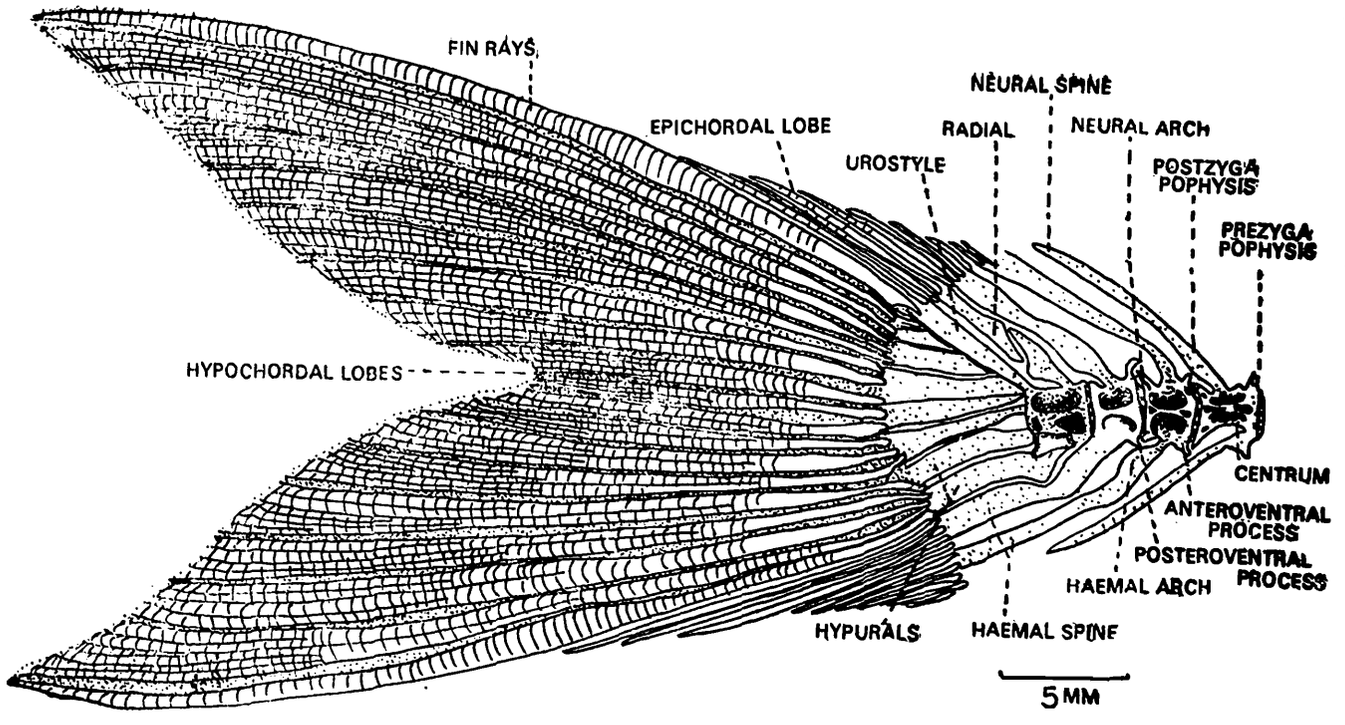


FIG 276

inclined anteriorly. On the contrary, in the occasional bottom feeders like *Schizothoraichthys* spp., and in purely column feeders like *Rasbora daniconius* and *Aspidoparia morar*, this bone is straight and takes part in lengthening of the skull. In *Labeo dero* and *Garra lamta*, the supraethmoid is inclined at an angle of 30° at its articulation with the frontals. The angle of inclination in *Schismatorhynchus nukta* is 85° which is the most highly evolved stage. Sahota (1970) has also reported an inclined angle of the supraethmoid in *Labeo dero*.

Ethmoid : The present study reveals that in the schizothoracine fishes, the ethmoid is protruded beyond the supraethmoid and gives an extra support to the projected prevomer which results in strengthening of the anterior part of snout. On the other hand, in cyprinine and rasborine genera, this bone hardly protrudes beyond the supraethmoid and forms an elevated platform for the latter. Harrington (1955) also observed a flared anterolateral ethmod in *Notropis bifrenatus* which conforms to the median notch of the prevomer underneath. The depression of snout is of advantage to the hill-stream bottom dwelling forms, viz. *Garra lamta*, for least resistance to swift water currents. In line with this, the ethmoid is also deeply depressed in this species. On the contrary, there is no such necessity for the dorsoventral depression of the snout in the column dwellers, viz. *Labeo dero*, *Rasbora daniconius* and *Aspidoparia morar*. Thus, the ethmoid in these fishes is consequently elevated.

Kinethmoid : The triangular, plate-like kinethmoid in *Rasbora daniconius* which rests on the broad saucershaped supraethmoid gives an extra attachment to the latter. In all the other species, this bone has narrowed into a rod. The length of rod is much reduced in bottom dwellers like *Garra lamta*. The reduction is compensated by the elongation of sigmoid ligament, the chief function of which is to move the premaxillaries for scrapping off algal material (Sagemehl, 1891 and Hubendick, 1942).

Prevomer : The present study reveals that the anterior part of the prevomer is usually broad and wide in the representatives of Schizothoracinae and Cyprininae. In *Garra lamta*, it is greatly expanded anteriorly as also in *Garra mullya* (Ramaswami, 1952a). This part of the prevomer serves to strengthen the anterior part of the snout. A characteristic hood, thus, formed in *Ptycobarbus conirostris*, *Garra lamta*, *Labeo dero* and *Schismatorhynchus nukta* appears to give an extra support to the snout to face swift currents. Posteriorly, the prevomer folds over to contact the parasphenoid in all the genera but the degree of its posterior extension has not been explained by any worker which appears to be very important from the systematic point of view.

Lateral ethmoid : This bone contributes nearly the entire face of anterior part of the orbit in the schizothoracine and cyprinine genera. In rasborine genera, it is much reduced. The well developed lateral process of lateral ethmoid forms the anterolateral part of orbit in the former two cases. A small conical projection arising from the anterior face of the lateral process in these species fortifies the posterior wall of the olfactory chamber. The lateral ethmoid in them is also broad and strong and strengthens the anterolateral walls of the orbit. Due to reduction of the lateral process in rasborine genera, this bone shares a little in the formation of orbit's posterior face. It appears that the lateral ethmoids in the hill-stream fishes are able to withstand the strong water currents better.

Preethmoid : The preethmoid fits into a fossa formed by the prevomer and ethmoid which is in agreement with the views of Starks (1926) and Howes (1978) but contradicts Harrington (1955) who considered that the preethmoids are exclusively supported by the prevomer. Ramaswami (1955a, b) held the view that it is supported by the ethmoid only. The position of the preethmoid is of taxonomic importance. In the schizothoracine, rasborine genera and *Garra lamta*, it occupies much of the anterior part of prevomer and adds to the lengthening of the skull. In *Labeo dero* and *Schismatorhynchus nukta*, it comes to lie on the posterolateral aspect of prevomer.

II. *Basicranial Region* :

Parasphenoid : Various gradations in the thickness of parasphenoid could easily be made out in each genera during the present investigations. These can be categorised into (i) broad parasphenoid (ii) thin, strut-like parasphenoid and (iii) the intermediate form. The present authors do not agree with the views of Ramaswami (1955b) who stated that the parasphenoid does not show much variations in cyprinids. The broad parasphenoid found in *Schizothoraichthys esocinus* conforms to the views of Howes (1978) that it is characteristic of piscivorous forms. However, similar nature of parasphenoid in *Garra lamta* is indicative of its dorsoventral depression. It can safely be conjectured that in the latter case, it is an important hill-stream adaptation. As Hora (1936) stated such an adaptation in *Garra* provides strength and solidity to the anterior part of snout which is so essential for its survival.

The thin, strut-like parasphenoid in *Rasbora daniconius* and *Aspidoparia morar*—purely column feeder feeding on microplanktonic orga-

nisms is itself an explanation that it lends very little support to the snout when the fish is feeding.

The intermediate type of parasphenoid is observed in majority of the schizothoracine genera, *Labeo dero* and *Schismatorhynchus nukta*— column dwellers and bottom feeders. Howes (1978) reported a wide parasphenoid in some species of *Labeo* studied by him. Thickness of parasphenoid in *Labeo dero* and *Labeo dyocheilus* (Lamba, 1966) is a good indicator of their food and feeding habits. *Labeo dyocheilus* which is purely a bottom feeder, has a much broader parasphenoid than that of *Labeo dero*.

Furthermore, it is observed that in the bottom living forms where skull is dorsoventrally depressed, the parasphenoid makes direct contact with the orbitosphenoid as in *Garra lamta* where the interorbital septum is altogether absent. Ramaswami (1952a) noted a small septum in *Garra mullya*. Howes (1978), however, reported the absence of such a septum in *Garra lamta* and *Garra blanfordi*. The interorbital septum is quite thin and large in column dwelling forms like *Rasbora daniconius* which are laterally compressed forms. A reduction in the septum is observed in the bottom feeders and column dwelling forms e.g. some schizothoracine fishes, *Labeo dero* and *Schismatorhynchus nukta*. These observations are quite in agreement with those of Howes (1978) who reported it in *Labeo coubie*.

Basioccipital : The various extreme modifications of the basioccipital in relation to the environment can be correlated to the pharyngeal teeth development and in turn to the food and feeding habits. The masticatory plate of the basioccipital is used as a grinding surface by the pharyngeal teeth (Regan, 1911). It has been noticed that the plate is highly developed in fishes where the mouth is slightly aterminal. According to the present studies, a broad masticatory plate is seen in *Sehizopygopois stoliczkae*, *Diptychus maculatus*, *Labeo dero*, *Schismatorhynchus nukta*. A similar broad masticatory plate has also been observed in *Labeo rohita* (Sarbáhi, 1933), *Labeo calbasu* (Bali, 1956), *Catla catla* (Rastogi, 1963) and *Puntius* (Vashist and Verma, 1968). The shape of mouth in these fishes suggests the omnivorous type of feeding, consisting of Ephemenoptern larvae and the algal slime. In the former case, the pharyngeal plate is more frequently used for grinding.

The masticatory plate in *Schizothoraichthys* spp., *Ptycobarbus conirostris* and *Schizothorax richardsonii* is slightly less devloped. The former two appear to be feeding on dead organic matter and mouth is used for browsing ; whereas the latter one feeds on algal slime and a little of Ephemenoptern larvae. In the herbivorus *Garra lamta*, the plate is

extremely reduced. In the microplankton feeders.—*Rasbora daniconius* and *Aspidoparia morar*—the plates are not wide. Vishwa Prakash (1972) also reported a weakly developed masticatory plate in *Barilius bendelisis* which are microplanktonic feeders.

III. *Qrbital Region*

Orbitosphenoid : The present study reveals that the orbitosphenoid shows a variable character in its length when compared to that of the pterosphenoid which is directly correlated with the compressed body. The greater the compression, the greater the ratio between the two. The orbitosphenoid septum (as already discussed in the parasphenoid) shows varying grades of development within the cyprinids studied, a view supported by Howes (1978). Its purpose is to provide wide separation between the cranial roof and the parasphenoid. Such a separation has little to do with the size of orbit but more with the angle at which the cranium is aligned to vertebral column and size of buccal cavity. In bottom living forms, due to dorsoventral depression of cranium, this bone is also compressed against the frontals.

Suborital series : The present investigations reveal the lacrymal (suborbital 1) is the largest bone of the series in schizothoracine fishes and *Garra lamta* and it probably strengthens the anterior part of snout. These observations are in conformity with those of Ramaswami (1948) on homalopterid fishes. In *Rasbora daniconius* and *Aspidoparia morar*, each lacrymal is smaller than the second suborbital, whereas the third suborbital is the largest of the series. Ramaswami (1955b), however, reported the expansion of second and thitd suborbitals in *Rasbora cuverii*. Tretiakov (1946) placed much empbasis in classifying the cyprinids on the basis of development of the suborbital series and suggested that those cyprinid genera with broadest posterior suborbital bones were the most primitive as is true of rasborine genera under report. The lacrymal in *Labeo dero* and *Schismatorhynchynchus nukta* is not wide and equals in length to the second suborbital. The present study reveals that number of suborbitals remains constant on each side, i.e. 5 but their shape and size vary according to the species, providing important taxonomic characters. Harrington (1955) and Roberts (1972) reported six suborbitals on each side in their studies on various cyprinids. Howes (1978) gave five as the constant number in the cyprinids.

Supraorbital : This bone is considered as the most reliable character in ascertaining the primitive or advanced nature of the particular taxon. The supraorbital in *Rasbora daniconius* and *Aspidoparia morar* extends

well back over the orbit and a close association between the supraorbital, autosphenotic and the fifth suborbital is maintained, a view supported by Gosline (1975) and Howes (1978). This condition is considered to be most primitive. In *Labeo dero* and *Schismatorhynchus nukta* each supraorbital is developed to cover about half of the orbit boundary whereas it is displaced anteriorly and is much reduced in the schizothoracine members and *Garra lamta* ; the connection of the supraorbital with the autosphenotic in them is thereby lost altogether. It, thus, appears that schizothoracine genera and *Garra lamta* are more advanced than rasborine genera. Harrington (1955) in *Notropis bifrenatus* compared it with an eyelid.

Frontal : The frontals are comparatively longer bones in the fishes which face swift currents of torrential streams of high altitudes as is the case in schizothoracine genera. Consequently, the length of the neurocranium is increased in these forms. In the cyprinine and rasborine genera, which inhabit the streams of low altitudes, avoid fast currents and hence, in them, the frontals are comparatively wider.

IV. *Otic Region* :

Supraoccipital : This bone is basically similar in all the cyprinids worked out but the occipital region of *Garra lamta* is comparatively smaller, and compressed, which appears to be a hill-stream adaptation. In *Aspidoparia morar*, much of the part of occipital region forms the dorsal part of roof of the skull, not observed in any other species.

The extent of posterior extremity of the supraoccipital towards the foramen magnum is an additional taxonomic character ; in some the supraoccipital almost reaches the foramen magnum as in *Diptychus maculatus*, *Labeo dero* and *Schismatorhynchus nukta* or it falls short as in other genera. Due to this feature, the shape of exoccipital is altered and this view is in full agreement with the comments of Howes (1978) in some species of *Labeo*. The supraoccipital spine varies in length. In schizothoracine and rasborine genera, the spine differs from that of cyprinine genera where it is in the form of a broad, raised, wing-like plate as is also reported by other workers, viz. Ramaswami (1955b), Sahota (1970) and Howes (1978).

Exoccipital : Present studies reveal that the vertical plate of exoccipital is large in rasborine genera due to which it encloses large lateral fenestra on each side. In *Garra lamta* and, to some extent, in other forms studied, due to the reduction of the vertical limb, lateral fenestra is much reduced which is an important hill stream adaptation. It appears that the muscles attached to these fenestrae provide extra

strength to the skull. Tilak (1961) also reported that occipital region of hill-stream fishes is strongly adhered to the anterior part of vertebral column for additional strength and compactness.

Autopterotic : From the present studies it is quite evident that the long and narrow autopterotic in schizothoracine genera and the narrow ones in rasborine genera, contribute towards the lengthening of cranial surface in comparison to the short and wide ones of cyprinine genera, a feature also noticed by Howes (1978) in *Barilius*. The contact of autopterotics to the frontals in all the genera (Ramaswami, 1955b and Howes, 1978) except in *Ptycobarbus conirostris* in the present studies, is an important character in taxonomy.

Autosphenotic : The present studies reveal that the autosphenotics develop below the frontals as shelf-like bones, contributing much to the dorsal roofing of cranium in schizothoracine fishes. In rasborine genera they contribute only a small part towards the dorsal roofing of skull. The cyprinine genera display a condition in which an antero-lateral process is given out on each side. The process is very well developed in *Garra lamta*. Similar processes have also been reported by Howes (1978) in *Esomus danricus*, *Catla catla*, some species of *Barbus* and *Labeo*. The ventral surface of the bone provides a fossa for the head of hyomandibular. In all the genera under report, there are two articular facets for the two heads of hyomandibular except in *Labeo dero* and *Schismatorhynchus nukta* where there is only one head of hyomandibular and similarly only one facet for the same. The extent of the share of autosphenotic in the formation of the fossa is different in all the species and is important taxonomically.

Epiotic : It has been observed that the posterior face of epiotic in schizothoracine genera, and to a smaller extent, in rasborine genera, is produced into a thick, caudally directed process. It is a feature associated with the lengthening of skull and supported by observations of Howes (1978) in *Erythroculter ilishaeformis*, *E. mangolicus* and *Schizothorax esocinus*. Due to the widening of epiotics in cyprinid genera, a large area is covered and with association of supraoccipital, it adds to the width of posterior cranial platform, as was noticed by Howes (1978) in *Elopichthys bambusa*. The high and spine-like crests of epiotics, so characteristic of some schizothoracine genera, have not been noticed in any other species under report. Due to the lengthenig of the occipital region of skull, the epiotic spines may be giving an extra support.

Opisthotic : The presence or absence of opisthotic is an important character in tracing the phylogeny of the group (Weitzman, 1962). During the present studies it has been noticed in a few schizothoracine

species, viz. *Schizothorax richardsonii*, *Ptycobarbus conirostris* and *Schizothoraichthys* spp. which is in agreement with the observations of Ramawami (1955b) and Howes (1978) in *Oreinus sinuatus* and *Schizothorax esocinus*. It therefore appears that these forms are specialized survivors of the unknown ancient group. Absence of opisthotics in rest of the species points towards their advanced nature.

Parietal : In forms which are directly in contact with swift currents, the parietals are small as compared to the frontals as in *Schizothorax richardsonii*, *Ptycobarbus conirostris*, *Schizothoraichthys* spp., and *Garra lamta*. Slightly longer parietals in *Schizopygopsis stoliczkae* and *Diptychus maculatus* suggest that these fishes cannot withstand a direct flow of swift water and thus are not highly evolved amongst the hill-stream forms. Of course, both forms occur at a very high altitude. It was observed that (personal communication) these fishes lie in marshy swamps along the river sides where the effect of strong current is nullified. In the midstream forms, the parietals are comparatively wide bones. Short and wide parietals have been reported by Howes (1978) in some species of *Labeo*.

2. BRANCHIOCRANIUM

(i) *Oromandibular Region* :

The modifications in the upper and lower jaws of fishes under study in relation to the kind of feeding habits are well represented by the corresponding modifications in the bones bordering the mouth as was also reported by Alexander (1966, 1967a, b, 1969). The major bones in this connection are the premaxillaries, maxillaries and mandibles.

Premaxillaries : The premaxillaries in all the fishes studied have either a rostral process or the same is absent. It has been observed that in bottom feeders like *Schizothorax richardsonii*, *Diptychus maculatus*, *Schismatorhynchus nukta* and *Garra lamta*, the process is either absent or much reduced. Ramaswami (1955b) also reported the absence of rostral process in *Diptychus maculatus*. *Ptycobarbus conirostris*, *Schizothoraichthys* spp., *Rasbora daniconius* and *Aspidoparia morar* have prominent rostral processes and possess terminal or slightly aterminal mouth (column feeders). The premaxillaries are usually the anterior most bones of the snout. But in *Garra lamta*, they come to lie ventrally.

Maxillary : As a rule, maxillaries do not form the anteriormost part of the snout but in *Garra lamta*, they come to lie anteriorly and are stoutly built. Structurally, the maxillaries are characteristically built in each species which can be considered as the most reliable

character in the field of systematics. On the dorsoposterior border of the maxillaries, there are two condyles in most of the genera, viz. *Diptychus maculatus*, *Schizopygopsis stoliczkae*, *Ptycobarbus conirostris*, *Schizothoraichthys*, *Rasbora daniconius* and *Garra lamta* ; while there is one condyle in *Labeo dero* and *Schismatorhynchus nukta*. These condyles rest on the antero-outer aspect of the respective autopalatine. The two equal condyles in *Diptychus maculatus* and *Garra lamta* probably ensure a safe and strong articulation. Ramaswami (1955a, b) and Howes (1978) also reported the presence of condyles in the maxillaries of the cyprinids. Usually, the rostral processes of maxillaries form a seat for premaxillaries. The quite apart portions of rostral processes of maxillaries of each side in *Ptycobarbus conirostris* provide a broad seat for the premaxillaries and long ligament connecting the two processes gives more elasticity to the sliding kinethmoid during protrusion of upper jaw. This is a deviation from its usual form of being directed medioanteriorly.

Dentary : Related with the modifications of premaxillaries and maxillaries, is the modification of the medial process of dentary which forms a mandibular symphysis. In *Schizothoraichthys* spp., *Ptycobarbus conirostris*, *Rasbora daniconius* and *Aspidoparia morar*, extent of symphysis is much less because lower jaw is somewhat elongated and the tip of the dentary is narrow while in fishes where the process of the premaxillary is absent, the symphysis is wide and tip of dentary is broad. Presence of a high ascending process in the lower jaw increases the power and speed at which the jaws could be closed and vice-versa in the species where the process is low, a view supported by Howes (1978). It is observed that the species where the process is low as in *Ptycobarbus conirostris* and *Schizothoraichthys esocinus*, show a carnivorous feeding.

Autopalatine : Howes (1978) has commented that the autopalatine in cyprinids varies a little but in fact it does, as is evident from the present studies. The main variations are noticed at its anterior head. The extent and the size of the articular facets on antero-inner aspect are variable and differ according to the size of maxillary condyles. The very long concavity of each autopalatine in *Labeo dero* and *Schismatorhynchus nukta* as compared to small concavity of all the other genera under study explains the fact that in these two species, the autopala tine, for most of its part, is attached to the prevomer and a smaller part to the preethmoid as the latter has shifted to posterolateral sides of the prevomer. The articulation of the maxillary condyles with each autopalatine through the intervention of enormous cartilage appears to be an efficient arrangement for resistance to flow of water as described by Tilak (1962).

The other bones of the oromandibular region, viz. the pterygoid series, the quadrate, the angular etc. show a uniform morphology as suggested by Ramaswami (1952a, b 1955a, b), Vishwa Prakash (1972) and Howes (1978).

(ii) *Hyobranchial Region* :

The present studies reveal that there is a uniform set of five pairs of elements in the hyoid cornua in all the genera showing a little variation. This statement is in agreement with that of Howes (1978). However, a few workers like Vashist and Verma (1968) in *Puntius*, Sahota (1970) in *Labeo dero* and Vishwa Prakash (1972) in *Barilius bola* and *B. bendelisis* reported the absence of interhyal in their studies. But it has invariably been found in the fishes under report.

Urohyal : It is an important bone which assumes various extreme shapes in the fishes studied and can be considered as an important taxonomic feature as it leaves enough possibility to distinguish the species from the other near related ones (Takaya, 1974). Yazdani (1976) asserted that urohyal is a bone which assists in respiration. Takaya (1974) opined that the urohyal helps the fish in ordinary movements of jaws. However, in the present study, it has been noticed that the urohyal is more associated with respiratory function and less so with the movements of jaws. In cyprinine genera, the horizontal wing of this bone is broad. As these fishes are available at low altitudes, the respiratory function is much more efficient, thereby supporting the view that the broad horizontal wing contributes a lot towards the respiratory mechanism. In the schizothoracine fishes which are available at high altitudes where plenty of oxygen is dissolved in water, due to their reduced respiratory function, the horizontal wing is not broad. The narrow horizontal wing in rasborine genera is due to their being laterally compressed forms. In these fishes, the large expanded vertical wing (keel) serves as an efficient respiratory organ.

Branchial arches : There is a uniform set of three rod-shaped basibranchials in schizothoracine and rasborine genera and characteristically two sets of umbrella-shaped basibranchials in the cyprinine genera as reported by Ramaswami (1955b). However, Vashist and Verma (1968), while studying the branchial baskets of *Puntius*, commented that the number of basibranchials is always two in carps. The statement is quite in conformity with the present work so far as the cyprinine genera are concerned but not true of other subfrmilies. The presence of two basibranchials is also reported by Sarbahi (1933) in *Labeo rohita*, Bali (1956) in *Labeo calbasu* and Rastogi (1963) in *Catla catla*. Others

elements of the branchial region show a uniform morpholoy as reported by Howes (1978).

Schizothoracine fishes inhabit high altitude where the oxygen contents are high ; therefore, these fishes retain water for longer time and branchial apertures are narrow due to which angle of ceratobranchials of two sides is quite large and hence, these are widely apart. Hora (1924), Jhangran (1975) and Jhingran *et al.* (1978) reported that the branchial apertures in hill-stream fishes are small which are probably the hill-stream adaptatlons. On the other hand, in the cyprinine and rasborine genera which are found at the foot hills where the amount of oxygen is comparatively low, large quantities of water enter the pharyngeal region through mouth to enable the fish to get enough supply of oxygen. Hence, their ceratobranchials are not widely apart or, in other words their angle is small.

Pharyngeal teeth : The structure of pharyngeal teeth suggests that in the herbivorous type of feeding, the teeth are weakly developed as in *Garra lamta*, while in omnivorous forms like *Schizothorax richardsonii*, *Diptychus maculatus*, *Schizothoraichthys* spp., *Labeo dero* and *Schismatorhynchus nukta*, these are well developed. In the plankton feeders like *Rasbora daniconius* and *Aspidoparia morar*, the teeth are not so strong. Lagler *et al.* (1962) considered that the teeth are absent in plankton feeders. The present observations are contrary to theirs. The number of rows of teeth and the number of teeth in each row are important characters which can be used in determining the primitive or advanced nature of the fish. Accordingly, the fishes with three rows of teeth are mor primitive as compared to those with two rows. However, this character cannot be independently used as a taxonomic feature although its additional significance cannot be ruled out. Chu (1935) and Vasnecov (1939) used it as an independent taxonomic character. However, the number of teeth rows was considered to be a variable character by Menon (1964) in some species of *Garra*.

Opercular bones : The present studies reveal that there is a uniformity in the number of elements comprising the structure as has also been reported by Ramaswami (1955a, b), Harrington (1955), Rastogi (1963), Dixit (1972) and Howes (1978). However, it is noticed that there is a marked range of differences in the height of operculum ; it is much reduced in schizothoracine genera. In cyprinine and rasborine genera, it is larger. Height of the operculum is also considered to be a hill-stream adaptation which can be correlated with the branchial chamber and in turn, to the ceratobranchials as well.

B. Weberian Apparatus

The structure of the Weberian apparatus is mainly dependent upon the body form of the fish and the latter is characteristically evolved in hill-stream fishes. The parapophyses of the fourth vertebra which are chiefly meant for holding the swim bladder in position, are modified according to the body form. The parapophyses are horizontally directed and strong in the species where the body form is much depressed dorsoventarlly as in *Garra lamta*. In the laterally compressed forms like *Rasbora daniconius* and *Aspidoparia morar*, the parapophyses are directed anteriorly and are long, thin and feeble. In forms like *Schizothorax richardsonii*, *Diptychus maculatus*, *Schizopygopsis stoliczkae*, *Ptycobarbus conirostris* and *Schizothoraichthys* spp., there is a tendency of dorsoventral depression of the body and the parapophyses are somewhat flat.

In *Labeo dero* and *Schismatorhynchus nukta*, the ventrally directed parapophyses are strong. The variation in the structure of the Weberian apparatus is helpful in ascertaining the systematic position of the genera, also reported by Tilak (1962, 1964), Vashist and Verma (1968), Sorescu (1975) and Howes (1978). There is a reduction in elements of the pars auditum in hill-stream fishes as reported by Tilak (1962, 1967). It is noticed that the tripus and transformator process are much reduced in *Garra lamta* whereas in *Labeo dero*, *Schismatorhynchus nukta*, *Rasbora daniconius* and *Aspidoparia morar* the transformator process is long and tripus is also large while in high altitude schizothoracine fishes, the condition is inbetween the two forms. Further, from the anterior end of parapophysis of fourth vertebra in *Ptycobarbus conirostris* arises a large rod-like process anteriorly which probably gives an extra support to the Weberian chain. This is an important taxonomic character not observed in any other species. A bipronged, hook-like process in the body of tripus in *Diptychus maculatus* is also an important diagnostic character which is not observed in any other genera. The short articular process of scaphium in *Garra lamta* and much longer one in *Labeo dero*, *Schismatorhynchus nukta*, *Rasbora*, *daniconius* and *Aspidoparia morar* and the intermediate type in the schizothoracine genera also conform to the above statement of reduction of elements of the chain in hill-stream forms. These obsevations are in agreement with those of Tilak (1962, 1967).

The second and third vertebrae in the fishes under report are fused to form a complex vertebra, a view supported by Ramaswami (1955a, b) and Howes (1978) ; however, Vashist and Verma (1968) reported the fusion of first three vertebrae in *Puntius*. Thus, it can be inferred that

Garra lamta with a nodule-like claustrum, reduced ascending process of the scaphium, a small intercalarium and short transformator process of the tripus stands highly evolved amongst the fishes studied. On the other hand, *Rasbora daniconius* with all elements well marked stands primitive. The rest of species fall inbetween them. This is further supported by the reduced size of the swim bladder in *Garra lamta* and longer one in *Rasbora daniconius*.

C. Girdles and Caudal Skeleton

Pectoral girdle : Due to the additional function of movements or adhering to rocks and to withstand swift currents, the pectoral girdle is also modifled to meet the respective demand of fish as also pointed out by Hora (1924, 1931). In the present studies it is noted that the cleithrum is large in high altitude forms and small in low land forms. This appears to be a hillstream adaptation to face the fast currents of water. Further, in bottom living forms like *Garra lamta*, the pectoral symphysis is very broad while it is narrow in column dwellers.

The small and medium-sized coracocleithral fenestra gives an explanation for the median rigidity and its contribution for adhering to rocks as examplified by schizothoracine genera and *Garra lamta*. The long coracocleithral fenestra in *Diptychus maculatus* suggests that median part of the pectoral girdle dose not serve the function of adhering and hence, it can safely be stated that this fish is mainly inhabitant of shallow pools along the sides of main stream but sometimes gets washed in currents of water. Shukla and Verma (1972) in *Barilius bola* have shown a wide gap at the articulation of the coracoid with the cleithrum, obviously referring to coracocleithral foramen.

Sorescu (1968) used the morphology of the pectoral girdles in differentiating the subfamilies of Cyprinidae. The present observations are in conformity with his report. Hora (1924) reported that there hardly appears any difference in bones of pectoral girdle of *Garra* and *Labeo*. But the present studies clearly point out that *Garra lamta* has a broad symphysis and a very reduced fenestra as compared to *Labeo dero* where the symphysis is short and fenestra is large.

Pelvic girdle : The structure of the pelvic girdle in hill-stream fishes is so designed as to provide an additional aid to the suckers and the pectoral girdle in adhesion. In the advanced hill-stream fishes, the basipterygium shows a tendency towards gradual enlargement as suggested by Saxena and Chandy (1965). The present studies reveal that anterior plates of basipteiygium are close to each other and the lateral fenestrae

are reduced in *Garra lamta* and *Schizothoraichthys* spp., as has also been reported by Saxena and Chandy (1965) in *Garra mullya* and *Psilorhynchus sucatio*. In the latter species, the anterior processes have broadened to such an extent that they meet and fuse with each other and the fenestrae are reduced to apertures. The fenestrae in forms like *Labeo dero*, *Schismatorhynchus nukta*, *Rasbora daniconius* and *Aspidoparia morar* are deep and basipterygial plates are weaker as compared to schizothoracine fishes, so the pelvic girdles are less used for adhesion as is the case in *Crossocheilus latius punjabensis* (Saxena and Chandy, 1965). Howes's (1978) remark that there is marked consistency in the structure of pelvic girdle in cyprinids does not find support from the investigations presented in this paper.

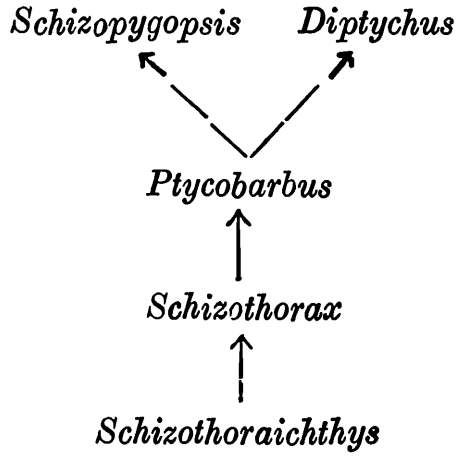
Furthermore, present studies reveal that due to a close similarity in various elements of the caudal skeleton in the species studied, this structure does not show much differences and can not be independently used as a taxonomic character as reported by Howes (1978).

PHYLOGENETIC CONSIDERATIONS

Hora (1937) and Menon (1974) have shown that the schizothoracine fishes are primitive as is evident from the fossil records available from Kashmir. Tyhey opined that these fishes whose fossils are known from the Karewas of Kashmir have probably spread along the Himalayas and further westwards during the second interglacial period, for better survival. Hora (1937) considered *Schizothorax esocinus* (*Schizothoraichthys esocinus*) to be the most primitive which existed in the lakes of Kashmir long times back and opined *Oreinus* (*Schizothorax*) to be its speacialised form. It is probable that in the ancient times, the fishes with a terminal mouth and having a piscivorous habit as examplified by *Schizothoraichthys esocinus* must have faced a difficulty to compete for food with the fishes of that area. From then onwards, the fishes might have started shifting towards feeding on dead organic matter settled at the bottom. This habit led to the use of pectoral and pelvic girdles for adhering to stones. The more evolved forms like *Schizothoraichthys micropogon* and *Schizothoraichthys labiatus* developed a slightly aterminal mouth which would have enabled these fishes to feed on dead organic matter as well as on bottom dwelling insect fauna. In *Diptychus macnlatus* and *Schizopygopsis stoliczkae*, position of the mouth still shifted ventralwards till a position found in *Schizothorax* was attained.

From the present osteological studies, it is quite appareni that due to the presence of opisthotics and three rows of pharyngeal teeth, i. e. 5, 3, 2-2, 3, 5, forms like *Schizothoraichthys* and *Schizothorax* can be

considered as primitive. By the absence of opisthotics and presence of two rows of teeth, i. e. 4, 3-3, 4, *Diptychus maculatus* and *Schizopygopsis stoliczkae* can be considered as their specialized forms. However, in *Ptycobarbus conirostris*, opisthotics are present but the pharyngeal teeth are in two rows, 4, 3-3, 4. Thus, *Ptycobarbus conirostris* can be considered intermediate between *Schizothorax* and *Diptychus* always considering *Schizothoraichthys* to be at its lowest level. The diagrammatic phylogenetic tree of schizothoracine fishes can be deduced as follows ;



Ramaswami (1955b) and Menon (1974) considered *Aspidoparia* as a cyprinine genera. However, others like Misra (1962), Hora and Mukerji (1970) and Gosline (1975) considered *Aspidoparia* as a rasborine genera. The present authors agree with the views of the latter authors as the osteological characters enumerated below clearly indicate its close relationship with *Rasbora* :

1. Large supraorbital clearly touching the autosphenotic.
2. Parasphenoid, a thin strut of bone.
3. Third suborbital being the largest.
4. Supraethmoid with a deep notch.
5. Tripus, long, dorsal rib of first vertebra extremely reduced, parapophysis of the fourth vertebra feeble and directed ventro-anteriorly.

Amongst *Aspidoparia morar* and *Rasbora daniconius*, the former appears to be slightly advanced over the latter as is evidenced by the following characters :

Aspidoparia	*Rasbora*
Deep but less wide groove of supraethmoid ; kinethmoid rod-shaped ; pharyngeal teeth 4,4,2-2, 4,4.	Deep saucer-shaped groove of supraethmoid ; Kinethmoid triangular, plate-like ; pharyngeal teeth 5,4,2-2,4,5.

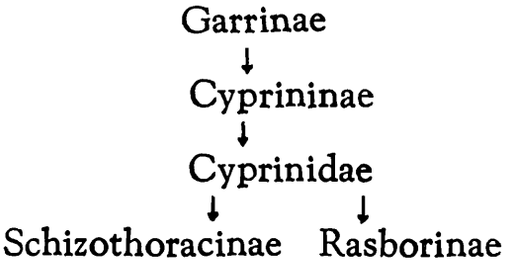
Present work further suggests that *Garra lamta* which is presently considered under the subfamily Cyprininae (Ramaswami, 1955 ; Misra 1962) can safely be placed in the subfamily Garrinae as opined by Smith (1945) and Nath (1980) ; while separating *Garra* in the present study, Ramaswami's osteological studies of *Garra mullya* (1952a) have also been taken into account. Following are the characters which can lead to its separation from Cyprininae :

1. Skull dorsoventrally depressed.
2. Supraethmoid notch completely absent.
3. Preethmoid on the anterolateral side of prevomer.
4. Parasphenoid broad anteriorly.
5. Pharyngeal plate extremely reduced with pointed pharyngeal process.
6. Maxillaries with two condyles and absence of any crochet-shaped process.
7. Parapophysis of fourth vertebra not ventrally directed ; ossa suspensoria splint-like.
8. Coracocleithral fenestra much reduced and pectoral symphysis much broad.
9. Basipterygial plates broad and strong, enclosing a small lateral fenestra.

These characters are sufficient enough to erect a new subfamily Garrinae as has been suggested by Smith (1945) and Nath (1980). Ventral mouth with a thick, broad and strong sucker at the chin ; dorsoventrally depressed head ; a complete absence of notch in supraethmoid are the characters sufficient from which it can be conjectured that forms like *Garra* are more advanced than these of *Labeo* and *Schismatorhynchus*. Furthermore, except from angle of inclination of supraethmoid with the frontal two forms show close similarity with each other in majority of osteological characters. Thereby, it is further suggested and interpreted that amongst the three cyprinine genera studied, *Garra* is the most advanced form. *Labeo* and *Schismatorhynchus* appear to be closely related sister genera.

So far as the subfamily status of the three subfamilies is concerned, these have originated from monophyletic stock of the family Cyprinidae. The subfamily Schizothoracinae is considered to be primitive having its independent origin near Rasborinae whereas Cyprininae also has its

independent origin. Subfamily Garrinae appears to be an advanced form of Cyprinidae. A diagrammatic phylogenetic tree of the subfamilies deduced is as follows :



SUMMARY

In order to study the systematic and phylogenetic position of three subfamilies, viz. Schizothoracinae, Cyprininae and Rasborinae, osteology of twelve Indian cyprinids has been undertaken. An endeavour has been made to justify the position of subfamily Schizothoracinae on the basis of osteological characters. These characters have been compared to those of subfamilies Cyprininae and Rasborinae. A workable key to these subfamilies and species, on the basis of osteological characters, has been enumerated. An evolutionary tree has also been drawn to show the position of the three subfamilies.

While taking into account the osteological characters of the three subfamilies, it can be concluded that Schizothoracinae which has its origin near subfamily Rasborinae, can also be considered as primitive due to the presence of opisthotics and three rows of pharyngeal teeth in some of its primitive forms like *Schizothorax* and *Schizothoraichthys*.

The subfamily Rasborinae can be considered as primitive amongst the three due to the presence of a shallow or wide notch of the supraethmoid, large supraorbitals touching the autosphenotics and three rows of pharyngeal teeth.

Cyprininae can be considered as slightly advanced than the two subfamilies, having its origin slightly above them. It resembles Rasborinae and Schizothoracinae in having only three rows of pharyngeal teeth and in majority of other characters, it shows advancements. The studies on Cyprininae show that *Garra lamta* is highly advanced amongst hill-stream forms. The advancement of *Garra lamta* over others is justified by the fact that in *Garra lamta* most of the bones show either characteristic fusion or reduction in processes of various bones. Various characters which can be considered towards its adaptation to torrential currents of water are depressed skull, small branchial aperture and wide branchiostegal rays, reduced size of the Weberian ossicles and the

coracocleithral fenestra of the pectoral girdle. Due to its great diversion of characters from the other cyprinine genera, a new family Garrinae has been resurrected for reception.

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