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Adipose Fin Cartilage Found in Some Teleostean Fishes

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Abstract Adipose fins of 33 species belonging to the Salmoniformes, Cypriniformes, Siluriformes and Myctophiformes were studied. Cartilaginous structure was found in the base of the adipose fin in 14 species of the Salangidae, Osmeridae, Plecoglossidae, Myctophidae and Neoscopelidae. In the Osmeridae, the cartilaginous structure can be divided into two types: a rather large slender cartilage observed in *Spirinchus*, and a small pear-shaped cartilaginous structure observed in *Thaleichthys*, *Osmerus* and *Hypomesus*. The former is similar to that of the Salangidae. The latter is similar to the cartilage of the Plecoglossidae in shape and location. In the Myctophidae and Neoscopelidae, cartilage and chondroid tissue are ventrally inserted in the underlying muscle layer, and different from the cartilaginous structure found in three families of the Salmoniformes in morphological characters.

As far as it was observed, no cartilaginous structure was detected in the adipose fin of fishes belonging to the families Salmonidae, Retropinnidae, Prototroctidae, Aulopodidae, Synodontidae and Chlorophthalmidae, suborders Argentinoidei and Characoidei, and the order Siluriformes.

The adipose fin is a small fleshy fin, which usually lacks endoskeletal supports. It is located between the dorsal and caudal fins, except for some fishes such as *Chauliodus* in which a ventral adipose fin is present in front of the anal fin in addition to the dorsal adipose fin. According to Nelson (1976), the adipose fin is found to occur in fishes of relatively lower orders, for example, the Salmoniformes, Cypriniformes, Siluriformes, Myctophiformes and Percopsiformes.

In regard to the structure of the adipose fin, Kosswig (1965) and Weisel (1968) showed histologically that this fin is composed of epidermis, dermis, loose connective tissue, actinotrichia as supporting elements and sometimes fat droplets. Typical fin rays are rarely observed in the adipose fin of some fishes belonging to the Characoidei (Cypriniformes) and Siluriformes. In these cases, however, there is no connection of fin rays to the underlying endoskeletal elements (Kosswig, 1965). In some siluroid fishes, the adipose fin bears a spine on the anterior margin, but it is an enlarged bony scute (Kosswig, 1965). Sandon (1956) reported a specimen of *Synodontis membranaceus* having an adipose fin with fin rays and pterygiophore-like bones, but that specimen seemed to be abnormal.

Thus no adipose fin with pterygiophores has been observed in normal specimens of any species. We found, however, that some fishes are provided with cartilaginous structures in the base of the adipose fin. In addition, our examination revealed different some types of cartilaginous structures in the adipose fin. In this paper we describe the morphology of the cartilaginous structures, and discuss possible usefulness of this peculiar structure as a taxonomic character.

Materials and methods

Materials examined in this study were 33 species belonging to the Salmoniformes, Cypriniformes, Siluriformes and Myctophiformes (Table 1). Some of these were from the collections of the Department of Fisheries of Kyoto University and the Fisheries Research Station of Kyoto University. They were preserved in formalin solution. Others were obtained from various sources during 1980 and 1981, and fixed in 10% formalin solution or Bouin's solution.

In classification of these fishes, we followed Nelson (1976), Sterba (1977), McDowall (1980) and Tominaga and Uyeno (1981).

For staining bone and cartilage, whole specimens were cleared and stained by the method of Dingerkus and Uhler (1977). For histological examinations, muscular blocks including the adipose fin were dissected out and paraffin sec-

Table 1. List of fishes examined and the occurrence of cartilaginous structure of adipose fin. +, present; −, absent.

Order/Suborder/Family/Species	No. of specimen	Body length (mm)	Cartilaginous structure
Salmoniformes			
Salmonoidei			
Salmonidae			
Oncorhynchus masou (Brevoort)	3	70～150	−
Salmo gairdneri Richardson	2	154～178	−
Salvelinus pluvius (Hilgendorf)	1	167	−
Retropinnidae			
Retropinna retropinna (Richardson)	1	94	−
Prototroctidae			
Prototroctes manaera Günther	2	160～164	−
Osmeridae			
Spirinchus lanceolatus (Hikita)	2	131～144	+
Thaleichthys pacificus (Richardson)	2	207～209	+
Osmerus eperlanus mordax (Mitchill)	7	132～228	+
Hypomesus pretiosus japonicus (Brevoort)	4	90～152	+
H. transpacificus nipponensis McAllister	4	60～105	+
Plecoglossidae			
Plecoglossus altivelis Temminck et Schlegel	14	12～131	+
Salangidae			
Salangichthys microdon Bleeker	6	71～ 80	+
Argentinoidei			
Argentinidae			
Glossanodon semifasciata (Kishinouye)	3	104～180	−
Bathylagidae			
Bathylagus sp.	1	120	−
Cypriniformes			
Characoidei			
Characidae			
Alestes sp.	1	92	−
Astyanax mexicanus (Filippi)	2	36～ 42	−
Hemigrammus ocellifer (Steindachner)	2	24～ 25	−
Serrasalmus sp.	1	34	−
Thayeria boehlkei Weitzman	2	27～ 29	−
Distichodontidae			
Distichodus sp.	1	137	−
Siluriformes			
Bagridae			
Pelteobagrus nudiceps (Sauvage)	1	88	−
Callichthyidae			
Corydoras paleatus (Jenyns)	2	30～ 31	−
Myctophiformes			
Aulopodidae			
Aulopus japonicus Günther	1	87	−
Synodontidae			
Synodus macrops Tanaka	2	111～114	−
Saurida undosquamis (Richardson)	1	82	−
Chlorophthalmidae			
Chlorophthalmus borealis Kuronuma et Yamaguchi	1	129	−
Myctophidae			
Benthosema fibulatum (Gilbert et Cramer)	1	58	+
Gonichthys venetus Becker	2	32～ 34	+
Myctophum spinosum (Steindachner)	1	35	+
Notoscopelus japonicus (Tanaka)	1	124	+
Stenobrachius nannochir laticaudus (Kulikova)	2	94～ 96	+
Neoscopelidae			
Neoscopelus macrolepidotus Johnson	3	90～138	+
N. microchir Matsubara	2	107～117	+

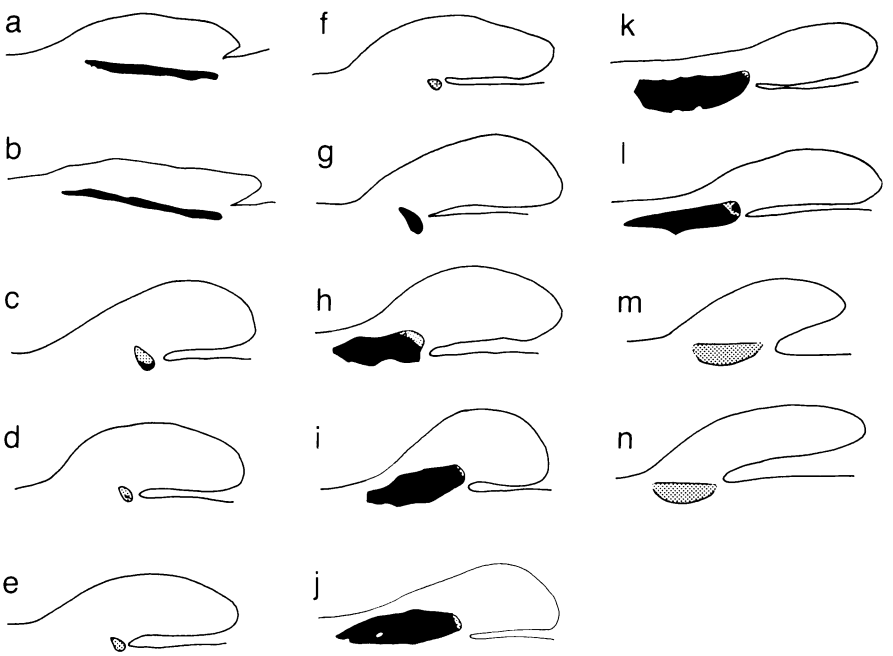

Fig. 1. Diagrammatics of lateral view of cartilaginous structure of adipose fin found in 14 species. Black area shows cartilage and stippled area shows chondroid tissue. (a): *Salangichthys microdon*. (b): *Spirinchus lanceolatus*. (c): *Thaleichthys pacificus*. (d): *Osmerus eperlanus mordax*. (e): *Hypomesus pretiosus japonicus*. (f): *Hypomesus transpacificus nipponensis*. (g): *Plecoglossus altivelis*. (h): *Benthosema fibulatum*. (i): *Gonichthys venetus*. (j): *Myctophum spinosum*. (k): *Notoscopelus japonicus*. (l): *Stenobrachius nannochir laticaudus*. (m): *Neoscopelus macrolepidotus*. (n): *Neoscopelus microchir*.

tions were cut transversely at a standard thickness of 7 μm. The sections were stained with alcian blue 8GX, Mayer's hemalum and eosin Although most of these specimens were adult fishes, some larvae and juveniles of *Plecoglossus altivelis* were also observed to estimate the stage of the formation of adipose fin cartilage.

Results

In 14 species of the Salmoniformes and Myctophiformes, the adipose fin is provided with a cartilaginous structure (Table 1). In the suborder Salmonoidei, all species of the Salangidae, Osmeridae and Plecoglossidae have a cartilaginous structure, but those of the Salmonidae, Retropinnidae and Prototroctidae lack this structure. It is absent in *Glossanodon semifasciata* and *Bathylagus* sp. of the suborder Argentinoidei. As to the Myctophiformes, the cartilaginous structure is present in all species of the Myctophidae and Neoscopelidae, but absent in members of the Aulopodidae, Synodontidae and Chlorophthalmidae. Fishes of the Characoidei (Cypriniformes) and Siluriformes lack adipose fin cartilage. The shape and location of the cartilaginous structure of the adipose fin in 14 species are illustrated diagrammatically in Fig. 1.

Salangidae. In *Salangichthys microdon*, a slender cartilage lies in the posterior two thirds of the adipose fin base (Figs. 1a, 2a). This is a typical hyaline cartilage lying beneath loose connective tissues, and forms itself into the basal axis of the adipose fin. In cross section it is a thin plate arching dorsally in the anterior half and depressed ellipsoid in the posterior half (Fig. 3a). The anterior part is often discontinuous.

Osmeridae. The adipose fin cartilage of *Spirinchus lanceolatus* is most prominent among the species of four genera of the Osmeridae. It is a slender plate consisting of hyaline cartilage,

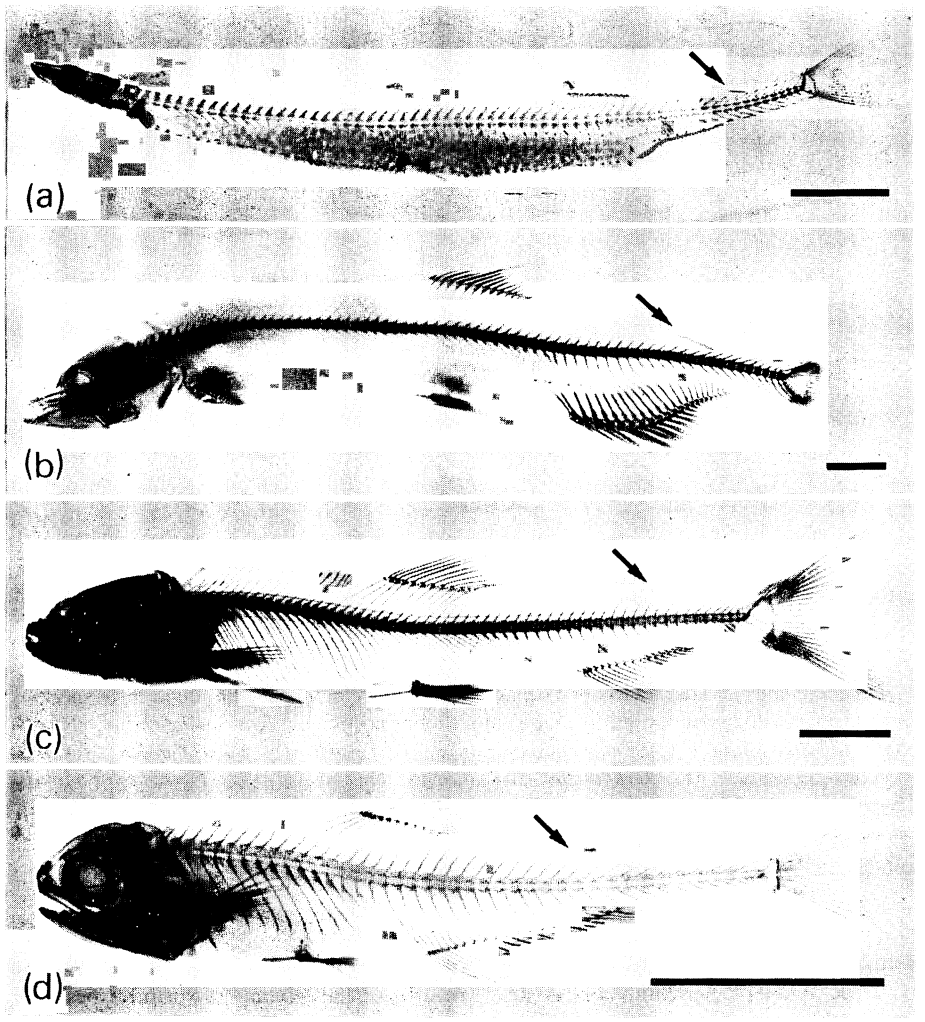

Fig. 2. Photographs of cleared and alcian blue-alizarin stained specimens showing adipose fin cartilage (arrows). Scale bars indicate 10 mm. (a): *Salangichthys microdon*. (b): *Spirinchus lanceolatus*. (c): *Plecoglossus altivelis*. (d): *Gonichthys venetus*.

and extends along almost the entire length of the adipose fin base (Figs. 1b, 2b). In cross section, it is a thin plate arched dorsally (Fig. 3b). It is often discontinuous near the anterior end, and sometimes perforated by minute foramina. On the other hand, in *Thaleichthys*, *Osmerus* and *Hypomesus*, the chondroid tissue (Maximow and Bloom, 1957) is rather prominent, and chondrification is partly seen as a small cartilage cell mass or a cartilage matrix in the tissue. This undeveloped condition of the cartilaginous structure differs from well developed hyaline cartilage found in *S. lanceolatus*. The chondroid tissue containing the cartilage cell mass or the cartilage matrix is small and pear-shaped, and located near the posterior end of the adipose fin base (Fig. 1c～f). In *T. pacificus*, the chondroid tissue contains fine fibers covering the cartilage cell mass (Fig. 3c). In *O. eperlanus mordax*, there is a small cartilage cell mass in the lower part of the chondroid tissue (Fig. 3d). In *H. pretiosus japonicus* and *H. transpacificus nipponensis*, a vestigial cartilage matrix is found in the central part of the chondroid tissue (Fig. 3e, f).

Plecoglossidae. In *Plecoglossus altivelis*, a

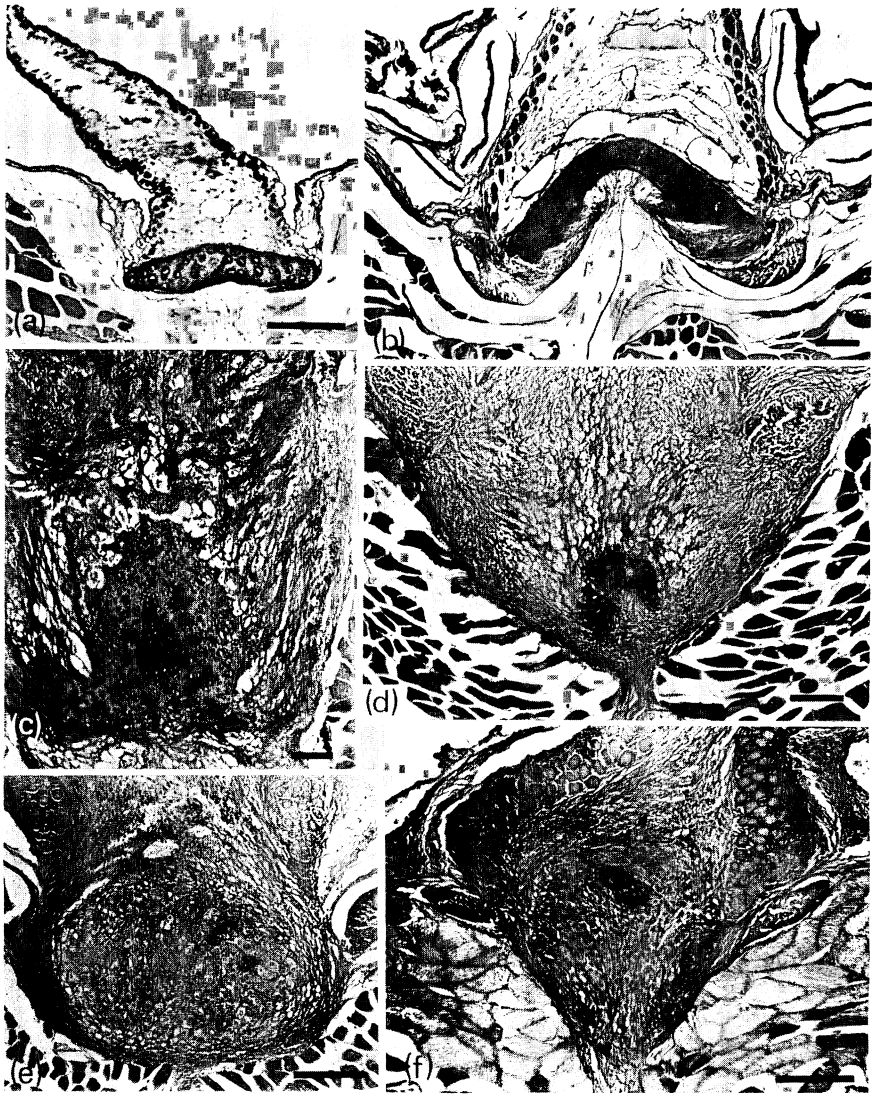

Fig. 3. Photomicrographs of cross sections through the basal part of the adipose fin showing adipose fin cartilage (a, b), chondroid tissue containing cartilage cell mass (c, d) and chondroid tissue containing cartilage matrix (e, f). Scale bars indicate 100 μm. (a): *Salangichthys microdon*. (b): *Spirinchus lanceolatus*. (c): *Thaleichthys pacificus*. (d): *Osmerus eperlanus mordax*. (e): *Hypomesus pretiosus japonicus*. (f): *Hypomesus transpacificus nipponensis*.

pear-shaped cartilage lies at an angle of about 60 degrees with the body axis in the posterior end of the adipose fin base (Figs. 1g, 2c). In general appearance this is very similar to that of osmerids except for *S. lanceolatus*, but this is composed of hyaline cartilage (Fig. 4a). In a 23.5 mm larva (body length), pterygiophores of the dorsal and anal fins are cartilaginous, but the adipose fin cartilage and predorsal bones are not chondrified. In a 31 mm BL specimen, chondrifications include the adipose fin cartilage and predorsal bones. No developmental changes are observed in the shape of the adipose fin cartilage.

Myctophidae. In fishes of five genera of the Myctophidae, the cartilaginous structures of the adipose fin are very similar to each other in shape. This structure is a compressed slender

cartilage with a small portion of chondroid tissue in the posterior end, and lies along the entire length of the adipose fin base (Figs. 1h～l, 2d). In *Benthosema fibulatum, Notoscopelus japonicus* and *Stenobrachius nannochir laticaudus*, there are several minute cartilages in the chondroid tissue located in the posterior end of the adipose fin cartilage (Fig. 1h, k, l). In *Myctophum spinosum*, a small foramen is present in the anterior part of the cartilage (Fig. 1j). Histologically this is composed of hyaline cartilage and the ventral edge extends deeply in the muscle layer along the dorsal midline (Fig. 4b).

Neoscopelidae. In two species of this family, *Neoscopelus macrolepidotus* and *N. microchir*, the cartilaginous structure of the adipose fin is not stained deeply by alcian blue (Fig. 1m, n). Histological sections show that the chondroid tissue containing networks of fine fibers extends to the entire length of the adipose fin base (Fig. 4c). The ventral edge of the chondroid tissue is sharply inserted in the muscle layer. In cross section, the chondroid tissue is wedge-like in shape, but posteriorly it becomes round in *N. macrolepidotus*, and trapezoid in *N. microchir*. However, no essential differences of this structure can be seen between these two species.

Fishes lacking cartilaginous structures. So far as our observations are concerned, the adipose fin lacks the cartilaginous structure in fishes belonging to the families Salmonidae, Retropinnidae, Prototroctidae, Argentinidae, Bathylagidae, Characidae, Distichodontidae, Bagridae, Callichthyidae, Aulopodidae, Synodontidae and Chlorophthalmidae. In these fishes, the core of the adipose fin entirely consists of loose connective tissue (Fig. 4d～f). In this type of adipose fin, there is no evidence of chondrification in the basal part, and the histological characters agree to those described by Kosswig (1965) and Weisel (1968).

Discussion

Although cartilaginous structures are found in the adipose fins of various fishes, it is absent in all members of some families in which the adipose fin is a common character. Its occurrence among fishes with the adipose fin shows a somewhat patchy pattern according to families, and the presence or absence of this cartilaginous structure may be indicative of phyletic relationships, at least in some families. The interrelationships of fishes of the Salmonoidei have been a subject of considerable discussion, and it is generally conceded that the Salangidae, Osmeridae and Plecoglossidae form a closely related group (Gosline, 1960; McDowall, 1969). Gosline (1960) combined these three Northern Hemisphere families with three Southern Hemisphere families, Aplochitonidae (including Prototroctidae), Retropinnidae and Galaxiidae, and placed them in the superfamily Osmeroidea. But he suggested that the northern Osmeroidea differ from members of southern ones in counts of branched caudal fin rays and other characters. Nelson (1976) placed the three northern families in the superfamily Osmeroidea and other southern families in the superfamily Galaxioidea, and included these together with the superfamily Salmonoidea in the suborder Salmonoidei. On the other hand, Rosen (1974) transferred the Galaxiidae (including Aplochitonidae) to the superfamily Salmonoidea, and placed the three northern families and Retropinnidae (including Prototroctidae) in the superfamily Osmeroidea.

It is interesting to note that the cartilaginous structure of the adipose fin is present in all species of the northern osmeroid families but is absent in the southern families, Retropinnidae and Prototroctidae. In comparing the hyobranchial and caudal skeletons, Rosen (1974) indicated close relationships of the salangids, plecoglossid, osmerids, retropinnids and prototroctids. But there are some differences between the group represented by the salangids, plecoglossid and osmerids, and that represented by the retropinnids and prototroctids, for example, morphological characters of the cartilaginous structure of the adipose fin and the number of branched caudal fin rays as noted above. Furthermore, there is a clear difference between these three northern osmeroid families and the Salmonidae so far as the cartilaginous structure is concerned.

In four genera of the Osmeridae, the cartilaginous structure of the adipose fin can be divided into two types in shape: a slender cartilage lying along the entire length of the adipose fin base, and small, pear-shaped cartilaginous structure lying in the posterior end of the adipose fin base. The former is seen in *Spirinchus*, and the latter is observed in *Thaleichthys*, *Osmerus* and *Hypomesus*. McAllister (1963) divided the Osmer-

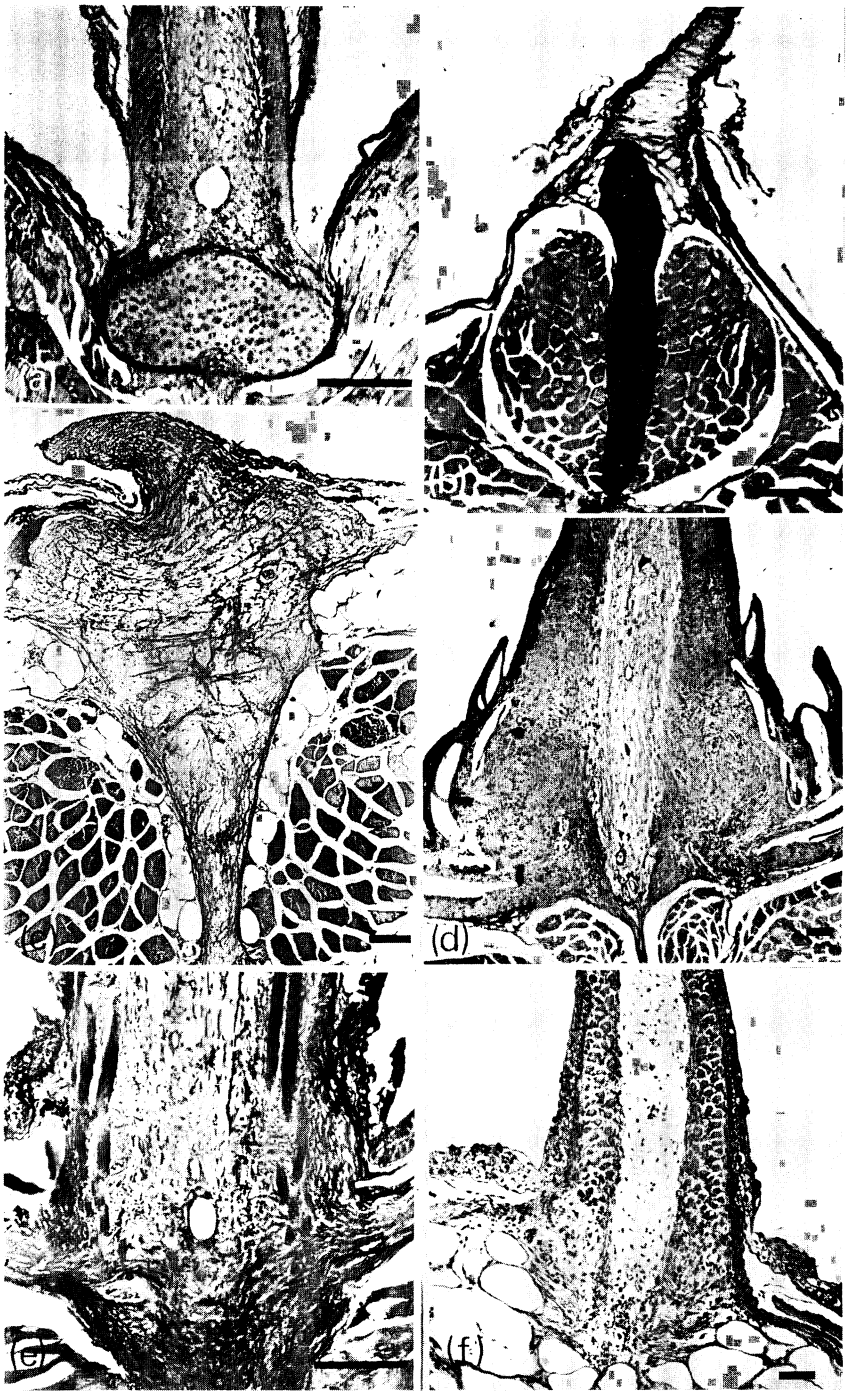

Fig. 4. Photomicrographs of cross sections through the basa· part of the adipose fin showing adipose fin cartilage (a, b), chondroid tissue (c) and absence of cartilaginous structure (d ~ f). Scale bars indicate 100 μm. (a): *Plecoglossus altivelis*. (b): *Gonichthys venetus*. (c): *Neoscopelus macrolepidotus*. (d): *Oncorhynchus masou*. (e): *Retropinna retropinna*. (f): *Astyanax mexicanus*.

idae into two subfamilies, Hypomesinae and Osmerinae, and placed *Spirinchus* in the most primitive position of the Osmerinae. Later he reexamined the systematics of the Osmeridae by a method of numerical taxonomy and suggested that *Thaleichtyhs* has a few more primitive characters than *Spirinchus* (McAllister, 1966). The fact that *Spirinchus* has considerably larger adipose fin cartilage compared to *Thaleichthys* and *Osmerus* may support the results of conventional taxonomy presented by McAllister (1963). In his diagram, Gosline (1960) indicated that the Salangidae form an early offshoot of the osmerid-plecoglossid lineage. The similarity of adipose fin cartilage between the Salangidae and *Spirinchus* suggests that *Spirinchus* is a more primitive member than other osmerid fishes.

It is generally considered that *Plecoglossus* bears a close relationship to the Osmeridae (Gosline, 1960; Iwai, 1974), and some authors reduced it to the subfamily of the Osmeridae (Norman, 1966). The adipose fin cartilage of *Plecoglossus*, is in shape and location, similar to the cartilaginous structure of *Thaleichthys*, *Osmerus* and *Hypomesus*, all referable to the Osmeridae, though the former is slightly larger and well chondrified. This common character may give evidence that *Plecoglossus* is more closely related to the osmerid fishes than to any other salmonoid fish.

The cartilaginous structure of the Myctophidae and Neoscopelidae differs from that of the Salangidae, Osmeridae and Plecoglossidae. It is a slender compressed plate and ventrally inserted in the muscle layer. The Neoscopelidae are said to be closely related to the Myctophidae (Fraser-Brunner, 1949; Moser and Ahlstrom, 1970; Paxton, 1972). Rosen (1973) removed the Aulopodidae and other related families from the Myctophiformes, and considered that this order comprises the Myctophidae, Neoscopelidae and a few Cretaceous species. In this regard, it seems to be a suggestive fact that the Myctophidae and Neoscopelidae share cartilaginous structures of the adipose fin. Fraser-Brunner (1949) considered the neoscopelids to be ancestry to the myctophids on the basis of the character of photophores. Greenwood et al. (1966) and Paxton (1972) pointed out that the Neoscopelidae have some advanced characters compared with the Myctophidae, for example, the presence of an enlarged distal process on the premaxillary and premaxillary-palatine ligament. Our observation that the cartilaginous structure of *Neoscopelus* is reduced to chondroid tissue may support the view of Greenwood et al. (1966).

There is no established theory concerning the origin of the adipose fin. According to Vasnetzov (1935, 1947), the adipose fin differentiates within the larval fin fold, but does not attain developmental completion. Kosswig (1965) suggested that this fin is regarded as a second dorsal fin or the posterior part of the dorsal fin. Gosline (1971) stated that the adipose fin is significant chiefly in the juvenile stage. Our observation on the development of adipose fin cartilage in *Plecoglossus altivelis* revealed that chondrification of this structure takes place at almost the same stage as that of predorsal bones, after chondrification of dorsal and anal pterygiophores. Since the predorsal bones of teleosts are considered to be homologous with the proximal pterygiophores of the dorsal fin (Smith and Bailey, 1961), the adipose fin cartilage is probably referable to undeveloped pterygiophores. Our investigation showed that among those fishes having an adipose fin, various states of development are found in the cartilaginous structure of the adipose fin, that is, hyaline cartilage, chondroid tissue and the loss of cartilaginous structure. Of particular interest is the reduced chondroid tissue found in the adipose fin of *Hypomesus*. This seems to be a vestigial state before disappearance of the cartilaginous structure in the adipose fin.

Occasionally, abnormal adipose fins with both fin rays and pterygiophores have been reported for some fishes. An unusual specimen having such supporting structures was described by Sandon (1956) for *Synodontis membranaceus*. Takashima et al. (1976) reported a second dorsal fin lying just behind a normal dorsal fin in some hatchery reared specimens of *P. altivelis*. Takashima (1976) noted that such an abnormal second dorsal fin with excessive fin rays in its anterior part in a larva measuring 25 mm in total length, looked like an adipose fin with fin rays having basal supports of cartilaginous masses. It is doubtful whether these cartilaginous masses are the same as the adipose fin

cartilage of our investigation, because the latter is not yet developed in normal specimens measuring about 25 mm in total length.

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硬骨魚類の脂鰭基部にみられる軟骨

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サケ目，コイ目，ナマズ目およびハダカイワシ目に属する33種の魚類について脂鰭の構造を調べた結果，サケ目のシラウオ科，キュウリウオ科，アユ科と，ハダカイワシ目のハダカイワシ科およびソトオリイワシ科に属する魚類の脂鰭基底部に軟骨あるいは軟骨様組織が認められた．しかしサケ目のサケ科，Retropinnidae, Prototroctidae, ニギス科，ソコイワシ科，ハダカイワシ目のヒメ科，エソ科，アオメエソ科，コイ目およびナマズ目に属する魚類には，このような組織は認められなかつた．サケ目の3科の魚類とハダカイワシ目の2科の魚類とでは，脂鰭軟骨の形態にかなりの違いがみられた．また，キュウリウオ科魚類の脂鰭軟骨の形態は2型に分けられ，一方はシラウオ科魚類のそれに，他方はアユ科魚類のそれに類似していた．

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