Some Contributions to Study of Esophageal Sacs and Teeth of Fishes

by

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Introduction

In the digestive system of some fishes the teeth may be found on the jaws, palatine, vomer, tongue, pharyngeal bones or gill arches, etc. There is a rare species of fish which have teeth in their esophagus. A part of the esophagus of these fishes contains a sac and there are tiny teeth (so-called esophageal teeth) in the inner wall of the sac. The sac is called an esophageal or a pharyngeal[1] sac, and KOSAKAI[2], one of present authors, reported that the sac was like a diverticulum of the esophagus. The gross anatomy and histology of the sacs and the teeth in only a few of these fishes have been described by GILCHRIST[3], BÜHLER[1], BERNARD[4] and KOSAKAI[2]. However, these authors could not obtain many kinds of fishes of this type and their histological investigations of the esophageal sacs and the teeth were not always adequate. This paper will contribute some additional morphologic observations about nine species of fish with esophageal sacs. Recently KOSAKAI[2] published in a Japanese language journal a paper on the esophageal teeth. Some parts of his study will also be included in this paper.

Materials and Methods

The materials of this study consisted of nine fishes as follows:

1. Psenopsis anorna (Psenopsis)
2. Ocycrius japonicus (Ocycrius)
3. Icticus pellucidus (Icticus)
4. Ariomma lurida (Ariomma)
5. Pampus argenteus (P. arg.)
6. Pampus echinogaster (P. ech.)
7. Nomeus albula (Nomeus)
8. Tetragonurus cuvieri (T. cuv.)
9. Tetragonurus atlanticus (T. atl.)

These fish names as abbreviated in the parentheses above were used in this paper. The first six fishes listed were the same as those investigated by KOSAKAI but the last three are described for the first time by the authors of this paper.

Unaided, visual and stereoscopic microscopical dissections were used to examine the esophageal sacs and included teeth. It was noteworthy that an antiformin* method

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* Sodium hypochlorite
deviced by KAWAHARA [5] was utilized in the dissection. It was possible with this method to liquefy soft tissues with antiformin, and to examine fine bony structures of esophageal sac walls.

On the other hand, the esophageal sacs were also removed, fixed with 10% formalin, decalcified with 5% nitric acid and embedded in paraffin. Seven micron thick serial sections were cut and stained with hematoxylin-eosin, MASSON’s trichrome and PAP’s silver ammonia for microscopic examination.

Observations

A. Esophageal sacs

The nine esophageal sacs included in this study showed two different shapes. One was a kidney and the other elliptical. The mucosae of the sacs were divided into two types, one had polypoid shaped processes and another appeared wrinkled (Figs. 1-4 & Table I).

Ocycrius, Psenopsis, Icticus, Ariomma and Nomeus had kidney shaped sacs and the sacs of T. cuv., T. atl., P. arg. and P. ech. were elliptical (Figs. 1 & 2). The sac walls were protected with thick muscular layers and the sac mucosa contained a fine supporting bone or cartilage. One can see esophageal teeth in the mucosa of seven of the nine fishes. T. cuv. and T. atl. are exceptions (Table I). The teeth were attached to the supporting bone with an attachment bone.

Fig. 1. Kidney shaped esophageal sac of Ocycrius japonicus, arrow shows esophageal sac.

Fig. 2. Elliptical shaped esophageal sac of Pampus argenteus, arrow shows esophageal sac.
### TABLE I
Classifications of Esophageal Sacs in Three Points of View

<table>
<thead>
<tr>
<th>Name</th>
<th>Shape</th>
<th>Mucosa</th>
<th>Teeth</th>
</tr>
</thead>
<tbody>
<tr>
<td>Ocycrius japonicus DODERLEIN</td>
<td>Kidney</td>
<td>Wrinkled</td>
<td>Teeth</td>
</tr>
<tr>
<td>Psenopsis anomala TEMMINCK et SCHLEGL</td>
<td>Kidney</td>
<td>Wrinkled</td>
<td>Teeth</td>
</tr>
<tr>
<td>Icticus pellucidus LUTKEN</td>
<td>Kidney</td>
<td>Wrinkled</td>
<td>Teeth</td>
</tr>
<tr>
<td>Arionna lurida JORDAN et SNYDER</td>
<td>Kidney</td>
<td>Polypoid</td>
<td>Teeth</td>
</tr>
<tr>
<td>Nomeus albula MEUSCHEN</td>
<td>Kidney</td>
<td>Polypoid</td>
<td>Teeth</td>
</tr>
<tr>
<td>Pampus argenteus EUPHRASEN</td>
<td>Elliptical</td>
<td>Polypoid</td>
<td>Teeth</td>
</tr>
<tr>
<td>Pampus echinogaster BASILEWSKY</td>
<td>Elliptical</td>
<td>Polypoid</td>
<td>Teeth</td>
</tr>
<tr>
<td>Tetrogonurus ceyieri RISSO</td>
<td>Elliptical</td>
<td>Polypoid</td>
<td>no Teeth</td>
</tr>
<tr>
<td>Tetrogonurus atlanticus LOWE</td>
<td>Elliptical</td>
<td>Polypoid</td>
<td>no Teeth</td>
</tr>
</tbody>
</table>

**Fig. 3.** Wrinkled mucosa of esophageal sac of Ocycrius japonicus.

**Fig. 4.** Polypoid mucosa of esophageal sac of Pampus argenteus.

### TABLE II
Classification of Polypoid Processes

<table>
<thead>
<tr>
<th>Name</th>
<th>Supporting Tissues</th>
<th>Form of Basel Bones</th>
<th>Ramification</th>
</tr>
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<tbody>
<tr>
<td>Nomeus albula MEUSCHEN</td>
<td>Bone</td>
<td>Radial</td>
<td>—</td>
</tr>
<tr>
<td>Pampus argenteus EUPHRASEN</td>
<td>Bone</td>
<td>Radial</td>
<td>—</td>
</tr>
<tr>
<td>Pampus echinogaster BASILEWSKY</td>
<td>Bone</td>
<td>Radial</td>
<td>—</td>
</tr>
<tr>
<td>Arionna lurida JORDAN et SNYDER</td>
<td>Bone</td>
<td>Scaly</td>
<td>—</td>
</tr>
<tr>
<td>Tetrogonurus ceyieri RISSO</td>
<td>Cartilage</td>
<td>—</td>
<td>Ramisiform</td>
</tr>
<tr>
<td>Tetrogonurus atlanticus LOWE</td>
<td>Cartilage</td>
<td>—</td>
<td>Ramisiform</td>
</tr>
</tbody>
</table>
(1) Polypoid process

The sac mucosa of Ariomma, Nomeus, P. arg., P. ech., T. cuv. and T. atl. had polypoid processes. A polypoid process covered with the mucous membrane of the sac was lined with a thin supporting bone or cartilage located in submucosa. The supporting bone or cartilage of each polypoid process was separated, and attached to a muscular layer of the sac wall with a little connective tissue. Polypoid processes of T. cuv. and T. atl. were supported by a cartilage and showed some ramifications (Fig. 5). Upon palpation one felt that the polypoid processes of this fish were elastic and softer than polypoids of other fishes. A supporting bone was found in the polypoids of Ariomma, Nomeus, P. arg. and P. ech. The supporting bone of the polypoid was a porous tube-like bone. The inner cavity of the porous tubes was occupied by fat cells and loose connective tissue. The bones supporing the polypoid processes of these four fishes were attached to the submucosa and muscles with special structures. That is, the supporting bones were divided into five to six fine radial processes close to the bottom of the polypoid processes parallel to the sac wall. They are called basal processes (Figs. 6 & 7). In Ariomma one can see another type attachment structure that is scale like (Fig. 8). These radial and scaly basal processes of each polypoid process were not
only out of contact each other, but radiated and occupied different levels of submucose (Figs. 6 & 8). Therefore, in the longitudinal sections of the polypoid they were observed as several layers of bone (Fig. 9).

On the other hand, in the fishes T. cuv. and T. atl. the polypoid processes were supported by a cartilage, and some ramified branches (Fig. 5). The supporting tissue of the polypoid was cartilaginous tissue, and changed to fibrous connective tissue in the base of the polypoid. The cells of the cartilage were like to hypertrophic cartilageous cells in bone formation (Fig. 10).

(2) Wrinkled mucosa

Wrinkled mucosa was found the esophageal sacs of Ocycrius, Penopsis and Icticus. The mucosa was also lined with a thin bony plate (supporting bone) in the connective
tissues under the epithelium. It was believed that each wrinkle consisted chiefly of the epithelium and the connective tissues containing the bony plate. However, a muscular layer was also found in some areas of the sac involved in the formation of the wrinkles (Fig. 11). Other detailed structures of the bony plate were not detected in this study.

**B. Esophageal teeth**

The teeth found on the esophageal sacs were attached to the supporting bone of the polyploid and wrinkled mucosa. The tips of the teeth penetrated through the mucosal epithelium and were exposed in the sac cavity. However, the esophageal teeth do not find in the sac of *T. cuv.* and *T. atl.* as mentioned above.

The esophageal tooth consisted of a homogeneous calcified tissue and pulp tissue. The calcified tissue was called homogeneous dentin by ISOKAWA [6] who studied scorpionfish teeth. This study could not show whether or not the dentin was covered with an enamel or an enamel-like substance. Dentinal tubules were not detected in the dentin. The structure of the homogeneous dentin was difficult to distinguish morphologically, from that of the supporting and attachment bones. This lack of differentiation occurred, because the dentin had no dentinal tubules and on the other hand, the bones were fibrous bones and there were no osteocytes in the bony tissues.

There was an area of contact between the dentin and the attachment bone (Fig. 12). The contact area described by ISOKAWA [7, 8] was composed of connective tissue fibers extending from the dentin to the attachment bone. The connective tissue pulp was enclosed by the dentin, the attachment bone and the contact area. In hematoxylin-eosin stained sections one could see a pink zone between the dentin and the pulp. Since human tooth predentin shows a similar uncalcified pink zone, this pulp margin area was named predentin in fish teeth.

In the outer surface of the pulp tissue there was a cell layer which contacted the predentin. In the early stage of dentinogenesis the cells were high columnar. The height of the cells became reduced with the progress of the dentinogenesis, and the cells eventually assumed a cubic form. It seemed that these cells were homologs of human odontoblasts and that these cells helped form the dentin. These odontoblasts had an oval nucleus in the basal end of the cell, and anastomosed with the protoplasmic process to

![Fig. 12. A esophageal tooth.](image)

**Fig. 12. A esophageal tooth.**

D: Dentin, P: Pulp, C: Contact area, A: Attachment bone.

![Fig. 13. Lattice like structure of sac wall muscle (tangential section).](image)

**Fig. 13. Lattice like structure of sac wall muscle (tangential section).**
surrounding connective tissue cells. None of the odontoblast had Tomes's fiber.

The odontoblasts, many connective tissue cells and blood vessels were found in
the newly formed pulpal tissue, but with the tooth formation these connective tissue
cells gradually disappeared, and the pulp tissue became fibrous. Finally the odontoblasts
also disappeared.

(3) **Muscular layers of sac wall**

The esophageal sacs had thick striated muscles along the sides attached to the
esophageal wall. The muscles were classified as two layers by GILCHRIST. The inner
layer was circular, the outer was longitudinal. This study verified the fact that the sac
wall showed in most instances two muscular layers, although in some areas only one
muscular layer was recognized. When the inner muscular layer of the sac wall was
cut tangentially, the layer showed a lattice like structure (Fig. 13). In general, the
muscles were not involved in the formation of the polypoid and wrinkled mucosa. How-
ever, it was occasionally noted that some wrinkled mucosa was associated with a small
mass of muscles (Fig. 11).

C. **Attachment bone**

The attachment bone has also been called the pedicle or bone of attachment by
some authors[9-11]. The attachment bone appeared to be a projection of the support-
ing bone, and it seemed to be formed by osteoblasts which looked like reduced odon-
toblasts. The attachment bone was fibrous and did not have lacunae and osteocytes in
the matrix. Many osteoblasts were seen along the bone margins in the formative stage,
but were reduced in numbers after the completion of the bone formation. The attach-
ment bone formed a short cylinder which was connected to the supporting bone under-
neath. The end of the attachment bone towards the esophagus or away from the
supporting bone supported a tooth with an attachment of connective tissue fibers. The
old attachment bone was resorbed with the growth and the eruption of a successional
tooth which developed under the attachment bone. When the successional tooth arrived
at the late stage of the eruption, a new attachment bone for the successional tooth was
formed by osteoblasts. When most of the old bone was resorbed, the old tooth was
also exfoliated.

**Discussions**

The fishes that have an esophageal sac are apparently uncommon. These fishes
and their sacs have apparently been little known for not many authors have made de-
tailed observations on esophageal teeth and the sac mucosa.

In T. cuv. and T. atl. not only are there no teeth in the esophageal sac, but one
finds supporting cartilages in their polypoid processes in stead of the supporting bones
seen in other fishes. As far as the authors know this paper may be the first report to
describe supporting cartilages instead of bone in the esophageal sacs of fish. It is hoped
that the material will contribute to a discussion of the evolution of these fishes. It may
be related to the function of the sac that the basal processes of the polypoids were each
at different levels and separated from each other (Figs. 6 & 8). It is possible that this
arrangement of the basal processes may have been well suited for the storage of the
fishes food in the esophageal sacs.

In Ocycrius, Psenopsis and Icticus the detailed structures of wrinkled mucosa lined
with the supporting bone was not studied.

MATSUBARA and TERAI[12] studied visually the esophageal sacs of seven fishes, and classified the sacs into four types. In this study, however, the sacs were classified into only two types in each category as shown in Table I.

According to BÜHLER the esophageal teeth have a enamel cap on the tip of the dentin, but one could not confirm the presence of an enamel cap in this study. It will be assumed that there was an enamel cap on the teeth as illustrated by BÜHLER. Recently ISOKAWA and SATOMURA[13] found that the tooth surfaces of porgies teeth excepting the tubular enamel area were covered with a very thin hypercalcified substance. It may be supposed that the surface of esophageal teeth were covered with such a thin substance.

It has been said in short that there are two muscular layers, circular and longitudinal, in the esophageal sac wall as well as in the human digestive tubes. However, it was reported by the present authors that the inner muscular layer attached to the basal processes of the polypoid have a lattice like pattern. The direction of this lattice-work arrangement of the muscles would more readily support the bony and cartilaginous basal processes.

In much of the literature on the study of fish teeth misleading terms are often used for the various parts of the tooth and their surrounding structures. It was necessary to decide on a better nomenclature for the study of fish teeth. The terms used with regard to various structures of fish teeth may have to be the same as those terms used by our predecessors in this field. However, in general, the same terms for the tooth and their surrounding tissues used in human dental histology will be used to describe fish teeth in comparative anatomy studies.

**Summary**

Nomeus, Psenopsis, Ocycerus, Icticus, Ariomma, P. arg., P. ech., T. cuv. and T. atl. have a esophageal sac. The structure of the sacs and the teeth found in the sacs were examined with conventional anatomical and histological methods. An antiformin method was also used in the dissection of the sacs.

The esophageal sac-cavities like diverticula communicated with the esophagus. Two shapes of sacs were found. Ocycerus, Psenopsis, Icticus, Ariomma and Nomeus had kidney-shaped sacs and the sacs of P. arg., P. ech., T. cuv. and T. atl. were elliptical. The sac wall was protected with thick muscular layers, the inner was circular and outer was longitudinal. The sac mucosa contained a supporting bone or cartilage. The inner surface of the sac mucosa of Ocycerus, Psenopsis and Icticus appeared wrinkled. Mucosal surfaces of Ariomma, Nomeus, P. arg., P. ech., T. cuv. and T. atl. had polypoid processes. The supporting cartilage was only recognized in the polypoid processes of T. cuv. and T. atl., and showed some ramifications. No esophageal teeth were found in these two fishes. The other polypoids lined with supporting bones had bony basal processes in their bases. The supporting bones were attached to the muscles of the sac-wall with basal processes. The basal processes showed two types of bases, one Nomeus, P. arg. and P. ech. had five or six radial processes, another Ariomma had a scale-like process. The supporting bones or cartilages were separated from each other.

Wrinkled mucosa also was lined with the supporting bone in the connective tissues under the epithelium.
Many tiny esophageal teeth were found in both the wrinkled and polypoid type mucosa excepting in the two fishes as mentioned above. Each tooth consisted of the homogeneous dentin and the pulp, but it was not clear whether they were covered with an enamel like substance. The tooth was fixed to the attachment bone by the supporting bone with a disc of connective tissue fibers (contact area).

(The authors wish to acknowledge to Dr. G. VAN HUYSEN, Professor of Anatomy, Indiana University School of Dentistry, and to Dr. T. ABE, Tokai Regional Fisheries Research Laboratory, Ministry of Agriculture and Forestry, for their suggestions.)

References