

Anatomy on the Opercular System of the Eel, *Anguilla japonica*

Kaworu NAKAMURA* and Kei-ichi MUSHIAKE**

Abstract

Preliminary study was performed anatomically as the base of the physiological approach to the respiration of the unilateral opercular movement. In eels, abductor muscles are recognized as the musculus masseter, m.abductor operculi anterior and m.abductor operculi posterior. The adductors are the m.adductor operculi and m.adductor radii branchiostegi. The former is innervated by each branch of the ramus maxillaris and r.facialis of the nervus trigeminus. The latter receives the r.facialis and r.hyoideus of the n.trigeminus. Respected muscles directly concerning with the unilateral opercular movement seem to be the adductors as the m.adductor operculi and m.adductor radii, and the medulla oblongata which is considered to be their primary nervous center participates probably its execution with the supposed especial function of the respiratory center.

Respiration of teleostean fishes is performed by five paired holobranches in the buccal cavity. Conduction of water current passing by the gill surface may be caused by two methods, that is, a branchial pump system and a propulsive movement. In such a classification, species as mainly depending on the former type have further two pump systems as an oral cavity and an opercular cavity. As for the oral pump, an increase of the cavity volume by the opening of the mouth causes an inflow of external water because of its negative pressure to the environment. Operculum begins simultaneously to abduct itself, then, the oral water has just been sucked into the opercular cavity because of its negative pressure compared to the oral cavity. As for the opercular pump, the opercular adduction causes the cavity volume of operculum to decrease, then, its positively yielded pressure to the environment pushes the cavity water off. At this time, the mouth is situated at the beginning to open and suck a fresh water into the oral cavity. With such a pump system, a regular opercular movement is concerned importantly. The opercular movement shows some differences among species, indicating the proper habits of fishes and their physiological individuality. As for example, its especial type can be taken up here among familiar fishes which have been objects for aqua-culture. That is an unilateral branchial respiration which has been reported only in eels. However concerning with this subject, no detail reports are present. Up to this time its introduction has been fragmentary and concomitant with the measurements of eel's respiration or oxygen consumption¹⁾²⁾.

* Lab. of Propagation Physiology, Fac. of Fisheries, Kagoshima University, Kagoshima, Japan.

** Lab. of Fish Pathology, Fac. of Applied Biological Science, Hiroshima University, Fukuyama, Japan.

The eel is a very important species in Japan, because of its widespread position on the fish culture. And at the standpoint of fishery management, it might be necessary and valuable to study the respiratory physiology and also especially above mentioned phenomenon of eels. In this report, a preliminary work was treated with anatomical methods for understanding the structural relation of the opercular movement. This work may become a base of physiological approaches in future.

Material and Method

Eels used in this study were 30–40cm in body length and were supplied by a fish culturist. They had been fixed previously with 10% formalin during some days. Dissection of the head region was performed with such tools as scissors, tweezers and double-edged blades. Under binocular or naked eye, the muscular constructions and their peripheral innervations of cranial nerves were recognized after cutting off the superficial dermis and relating tissues. As for tracing the nerve fibers, a weak solution of methylene blue was suitably used for an exact observation. If necessary, a skull and visceral arches such as gill filaments, basal line, branchial arches, hyoid arch, mandibular and palatine arches were exposed for the mechanical understanding of the oral and opercular movements.

Results and Discussion

1) Muscles unrelated directly with the opercular movement (Fig. 1 and 3)

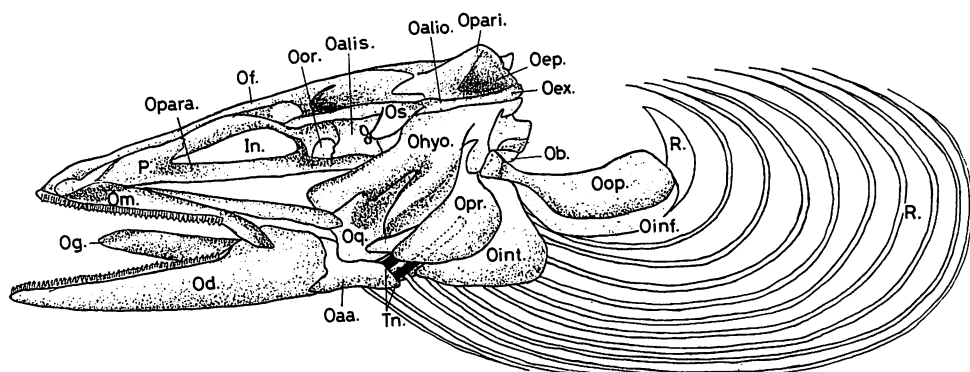
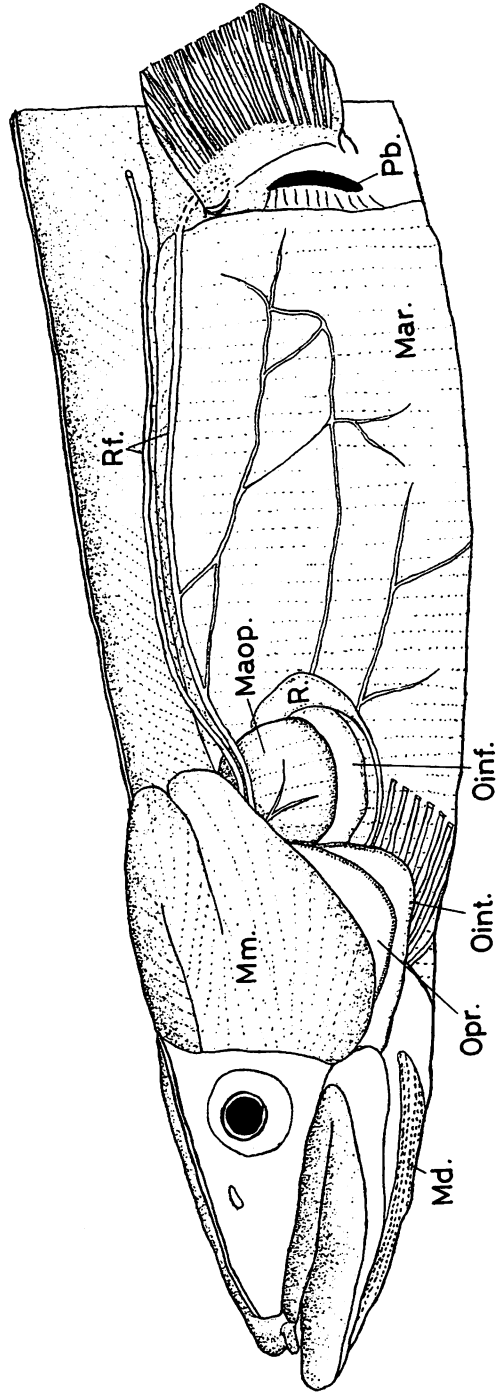
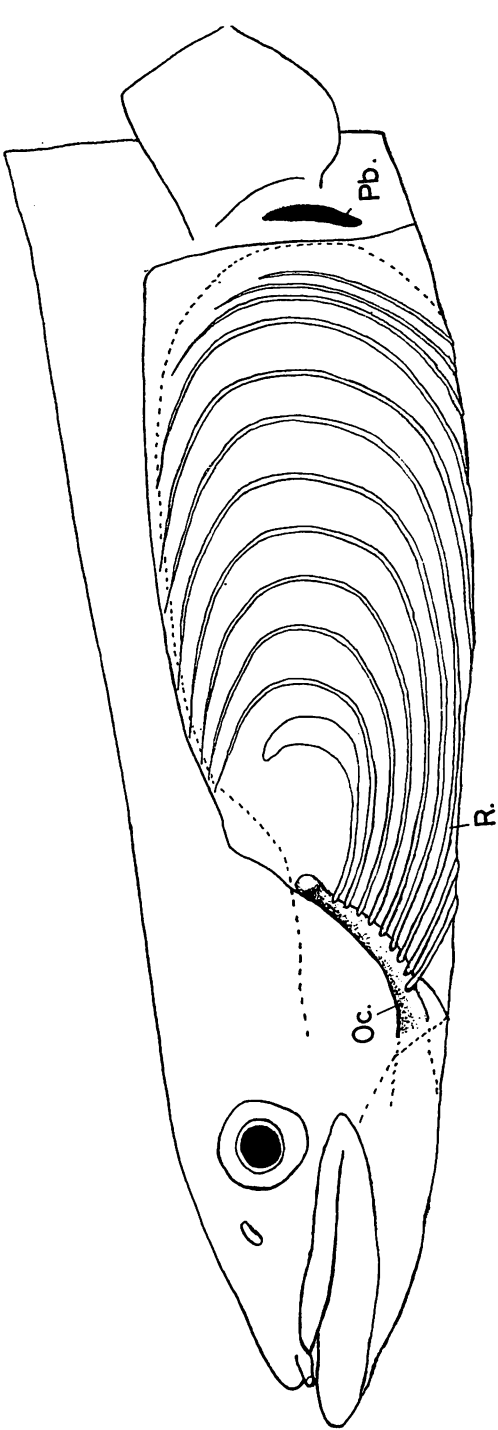


Fig. 1. Diagrammatic representation of the cranial bones of the eel, *A. japonica*. Abbrev., In. : interorbital opening, Oaa. : os articulare-angulare, Oalio. : os alioticum, Oalis. : os alisphenoideum, Ob. : os basioccipitale, Od. : os dentale, Oep. : os epioticum, Oex. : os exoccipitale, Of. : os frontale, Og. : os glossohyale, Ohyo. : os hyomandibulare, Oinf. : os infraoperculare, Oint. : os interoperculare, Om. : os maxillare, Oop. : os operculare, Oor. : os orbitosphenoideum, Opara. : os parasphenoideum, Opari. : os parietale, Opr. : os preoperculare, Oq. : os quadratum, Os. : os sphenoideum, P. : premaxillo-ethmovomerine plate, R. : radii branchiostegi, Tn. : tendon.



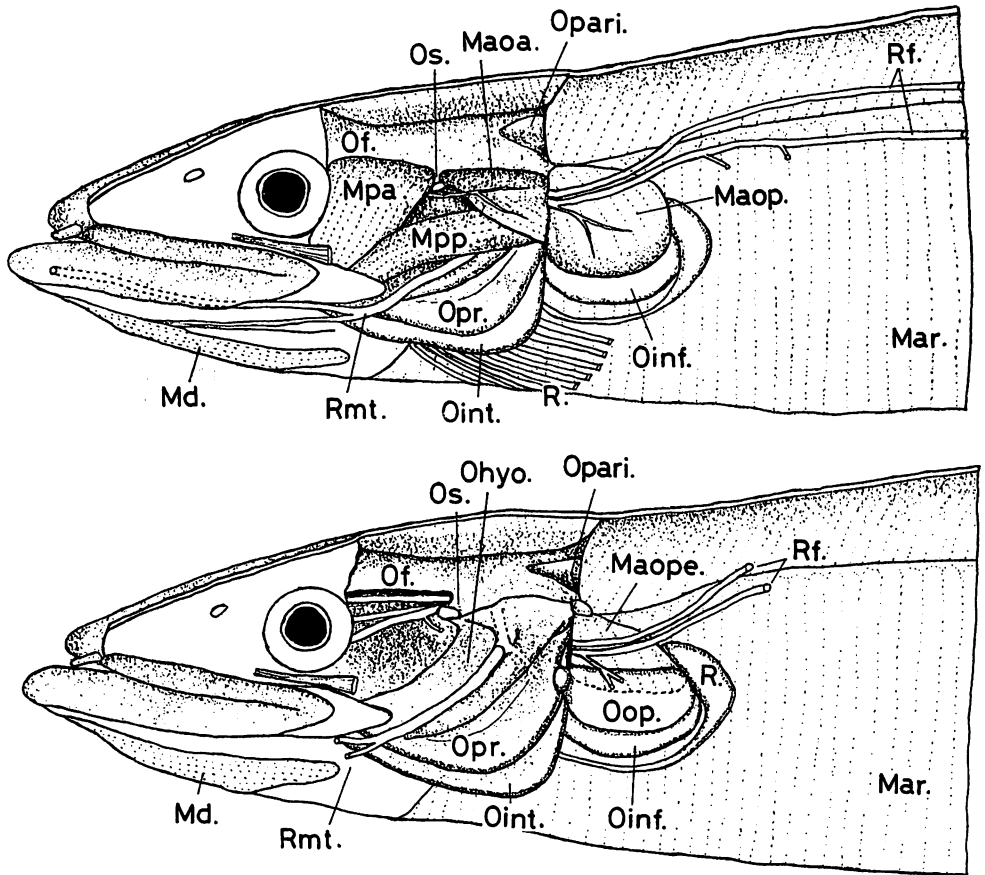


Fig. 3. Arrangements of the opercular abductors and adductors accompanying their related bones. Abbrev., Maa. : musculus abductor operculi anterior, Maop. : musculus abductor operculi posterior, Maope. : musculus adductor operculi, Mar. : musculus adductor radii branchiostegi, Md. : musculus depressor mandibule, Mpa. : musculus pterygoideus anterior, Mpp. : musculus pterygoideus posterior, Of. : os frontale, Ohyo. : os hyomandibulare, Oinf. : os infraoperculare, Oint. : os interoperculare, Oop. : os operculare, Opari. : os parietale, Opr. : os preoperculare, Os. : os sphenoidum, R. : radii branchiostegi, Rf. : ramus facialis, Rmt. : ramus mandibularis.

Fig. 2. Lateral views of the head region, showing the arrangement of radii branchiostegi deriving from the os ceratohyale (left), and some muscles and bones relating to the branchial respiration (right). Abbrev., Maop. : musculus abductor operculi posterior, Mar. : musculus adductor radii branchiostegi, Md. : musculus depressor mandibule, Mm. : musculus masseter, Oc. : os ceratohyale, Oinf. : os infraoperculare, Oint. : os interoperculare, Opr. : os preoperculare, Pb. : branchial pore, R. : radii branchiostegi, Rf. : ramus facialis of the nervus trigeminus.

Musculus pterygoideus anterior (Mpa.) attaches to the anterior part of the os alioticum (Oalio.) which is situated at the anterior to the o.sphenoideum (Os.), and also along to its antero-external edge. Contacting with the posterior inside of the o.maxillare (Om.), it attaches the other end to the posterior end of the o.dentale (Od.) through a tendon. It forms a dorso-lateral wall of oral cavity, and acts as a lifter of the mandible.

M. pterygoideus posterior (Mpp.) is situated at the posterior to the Mpa. and attaches to the dorso-posterior of the o.hyomandibulare (Ohyo.), then, advances antero-ventrally until it attaches the other end to the posterior of the Od. through a tendon.

M. depressor mandibule (Md.) attaches to the ventro-frontal end of the o.ceratohyale (Oc.) and the ventro-posterior end of the o.hypohyale (Ohyp.) and advancing along the ventral of the Od., it attaches the other end to the anterior end of the Od. . It shows ventrally a paired long ellipsoid shape. Contraction of this muscle induces the Od. to let down, then, the opening of the mouth occurs.

2) Muscles related with the opercular movement (Fig. 1, 2, 3, 5 and 6)

Musculus masseter (Mm.) attaches dorsally to the posterior of the o.frontale (Of.) and the anterior of the o.parietale (Opari.), also laterally to the posterior of the Om. and the dorso-posterior edge of the Od. . One of its functions is to adduct the Od. after lifting the Om. dorso-posteriorly. The other function is to lift the Ohyo. and the o.preoperculare (Opr.) to which the Mm. adheres respectively, then, also lift the o.interoperculare (Oint.), o.operculare (Oop.) and o.infraoperculare (Oinf.) which are connecting each other with the former by the membranous tissue. At the same time, the Ohyp. and Oc. which are connected with above mentioned opercular components are abducted accompanying lifted radii branchiostegi (R.) connecting to such hyoid bones. As a result, all of the opercular components are lifted by the contraction of the Mm. . In the case of the eel, this muscle shows a well developed mass just behind the eye orbit and occupies a relatively wide area in the dorso-lateral region.

M. abductor operculi anterior (Maoa.) shows an inverted triangular shape lying between the antero-external end of the Oop. and the postero-external edge of the Oalio., the latter through the tendon just behind the Os. . It abducts the Oop. so that the operculum is induced to open exteriorly.

M. abductor operculi posterior (Maop.) attaches to the apophysis of the dorso-posterior edge of the Ohyo. and at the other end to the ventro-exterior edge of the Oop. . It shows a swelled triangular shape, contacting with the Maoa. just posteriorly. It abducts the Oop. so that the operculum is induced to open exteriorly.

M. adductor operculi (Maope.) attaches to the ventral side of the apophysis of the dorso-posterior edge of the Ohyo. running inside the Maop. to the back side of the dorsal part of the Oop. . It adducts the Oop. following adduction of the relating Oinf., Oint. and Opr. . As a result, its function is to close the opened operculum.

M. adductor radii branchiostegi (Mar.) distributes its specialized thin muscle bundles on the lateral and ventral wide covering of the branchial cavity. Their running direction shows

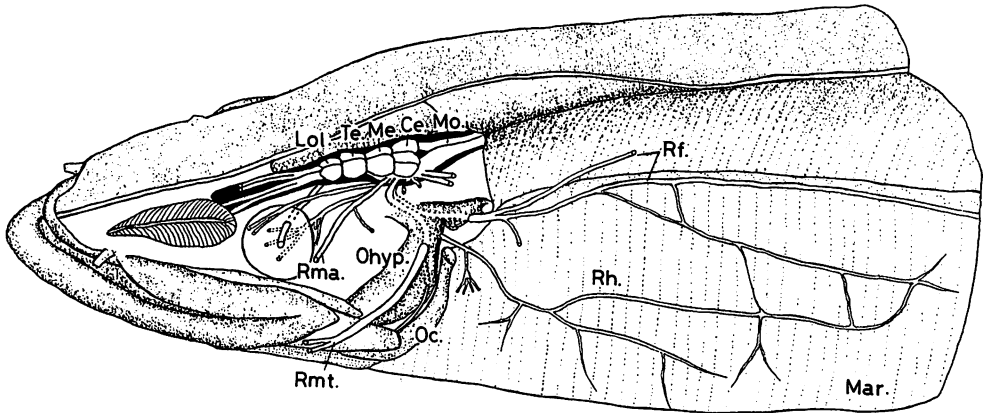


Fig. 4. Trigeminal nerves deriving from the brain and their branches innervated on the adductor muscle of branchiostegal ray. Abbrev., Ce. : cerebellum, Lol. : lobus olfactorius, Mar. : musculus adductor radii branchiostegi, Me. : mesencephalon, Mo. : medulla oblongata, Oc. : os ceratohyale, Ohyp. : os hypohyale, Rf. : ramus facialis of nervus trigeminus, Rh. : ramus hyoideus of n. trigeminus, Rma. : ramus maxillaris of n. trigeminus, Rmt. : ramus mandibularis of n. trigeminus, Te. : telencephalon.

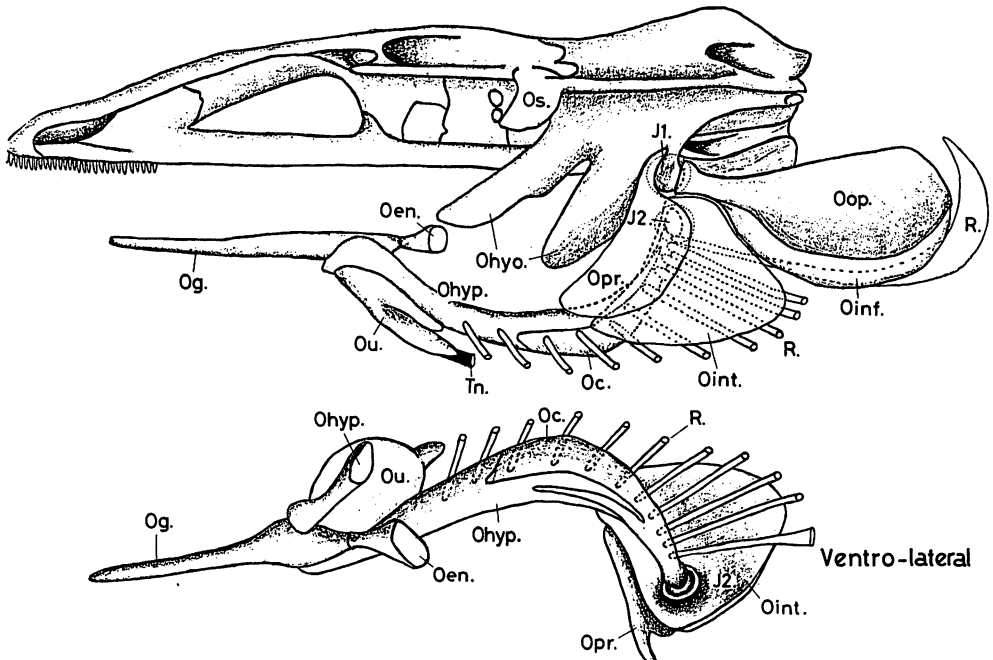
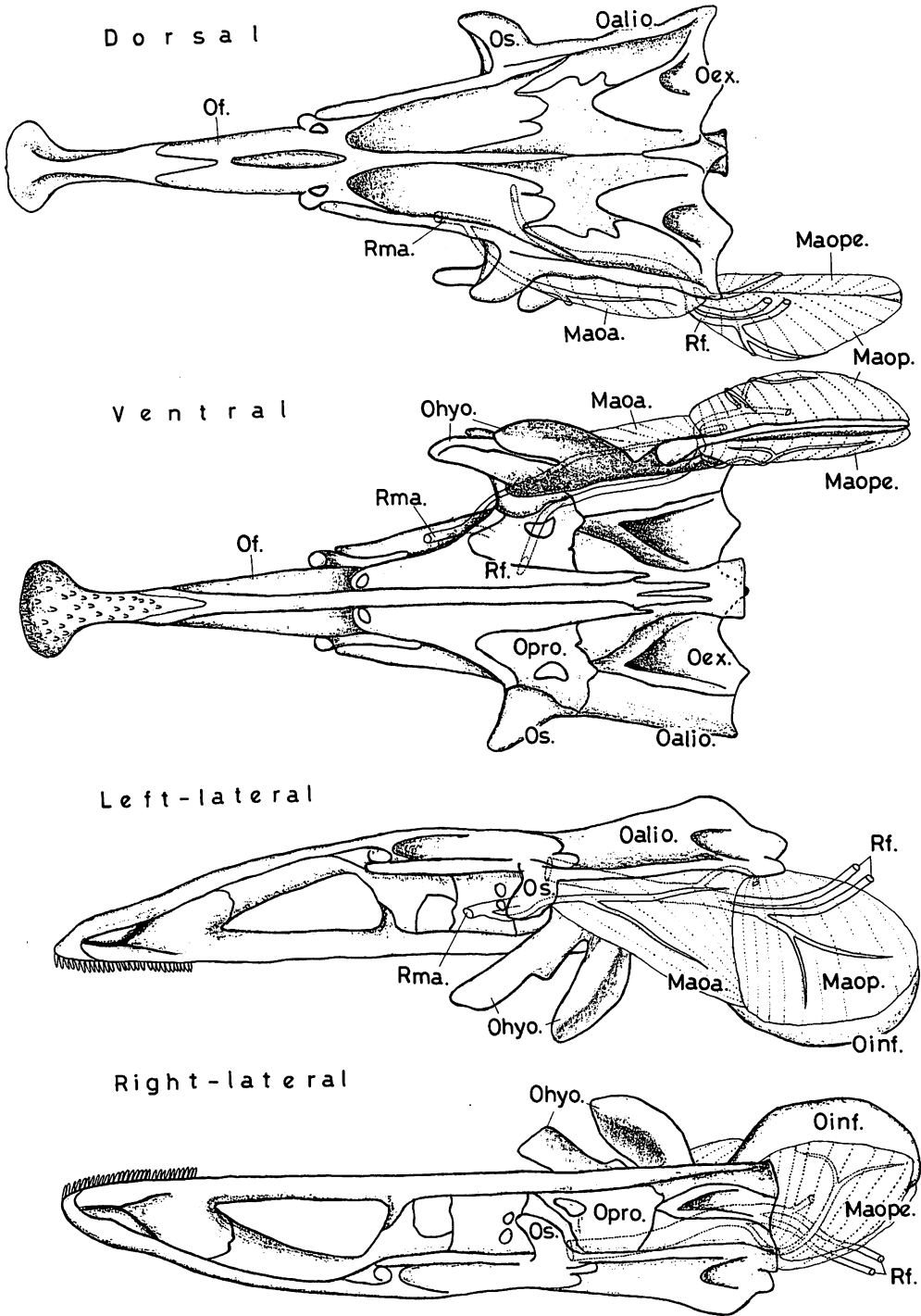


Fig. 5. Indicating two fulcra related to abduction and adduction of the opercular or interopercular bone. Joint 1 connects the Oop. with the apophysis of the Ohyo.. Joint 2 connects the Oint. with the Oc.. Abbrev., J1. : joint 1, J2. : joint 2, Oc. : os ceratohyale, Oen. : os basibranchiale, Og. : os glossohyale, Ohyo. : os hyomandibulare, Ohyp. : os hypohyale, Oinf. : os infraoperculare, Oint. : os interoperculare, Oop. : os operculare, Opr. : os operculare, Os. : os sphenoidum, Ou. : os urohyale, R. : radii branchiostegi, Tn. : tendon.



transversal to the body axis, and each serial covers completely the ventral region between the posterior edge of the o.articulare-angulare (Oaa.) and just before the gill slit. Rarii branchiostegi (R.) adheres laterally to the outer surface of this muscle arranging arciform rows supported with the membranous tissue. This muscle pulls interiorly the R. by its contraction. After that, each opercular component is induced to be adducted to shut the gill slit. In **Fig. 6**, such muscles relating with the opercular movement as the Maa., Maop. and Maope. are drawn to show their constructional relation. Further, their related bones are shown in **Fig. 5**. Contracted Maa. and Maop. abduct the Oop. and its connected bones through the membranous or tendon tissues at the two fulcra (J1. and J2. in **Fig. 5**). The Maope. adducts the opercular components at the above mentioned fulcra.

3) Nerves related with the opercular movement (**Fig. 4** and **6**)

Ramus maxillaris of the nervus trigeminus has its starting point at the ventro-anterior of the medulla oblongata, then, runs forward ventrally. After penetrating into the hole between the Os. and Oalis., it is divided into the Rma. of the main trunk and a branch. The latter branch changes its direction backward under the Os. and runs to the Maa. . It is divided again at its periphery.

R. facialis of the nervus trigeminus derives from the m.oblongata as the inferior branch of the n.trigeminus inside the Ohyo. It runs backward inside the Ohyo. and soon goes out of the latter. At that point, it is divided into two branches. Both of the branches go out of the space between the Maa. and Maope., and run backward on the surface of the Maop. . One of the divided branches, ventral branch, sends out a branch which innervates the Maop. at its periphery. Its main trunk runs backward along the dorsal edge of the Mar., then, passing by the posterior edge of the pectoral fin, reaches to the ventral area. On the way at the Mar., it sends out two branches ventrally which innervate the Mar. laterally and connects at its periphery with the r.hyoideus. The other one of the divided branches, dorsal branch, goes backward along the muscle surface of the body trunk.

R. hyoideus goes out of the hole of the Ohyo. after separating from the main trunk of the n.trigeminus and runs backward along the inside of the Oop. and also dorsally to the Oc. . At the past point of the Oc., it sends out a branch ventrally. This branch is divided into four branches at the hidden point under the R. . Each pair of these branches goes ventro-anteriorly or ventro-posteriorly at the anterior area of the Mar. . On the other hand, the main trunk of the r.hyoideus runs backward and soon divides itself after sending a branch one time. Ventral branch of this divided trunk innervates the ventro-lateral surface of the Mar. . Its dorsal branch

Fig. 6. Constructional situations of the abductor and adductor muscles of the opercular bone, innervated by the branches of trigeminal nerve. Abbrev., Maa. : musculus abductor operculi anterior, Maop. : musculus abductor operculi posterior, Maope. : musculus adductor operculi, Oalio. : os alioticum, Oex. : os exoccipitale, Of. : os frontale, Ohyo. : os hyomandibulare, Oinf. : os infraoperculare, Opro. : os prooticum, Os. : os sphenoidium, Rf. : ramus facialis of nervus trigeminus, Rma. : ramus maxillaris of n. trigeminus.

goes backward along the exterior surface of the Mar. and innervates the Mar. laterally. At its periphery, the dorsal branch connects with the r.facialis. Further at its terminal, each trunk of the r.hyoideus and r.facialis connects one another forming a trigemino-facial complex.

The eel has some specialized respiratory aspects as skin respiration, rest of opercular movement and unilateral branchial respiration. As for this unilateral branchial respiration, some observations have been reported. Eels can rest an one-sided opercular movement and its gill slit is induced to shut. Often at that time, the resting operculum (opercular area) becomes hollow contrary to the other side. Then, respiration is continued by the other side movement¹⁾²⁾. Respected muscles relating with such a process would be firstly adductors of operculum. They are the Maope. and Mar. . The Mar. seems to be more effective for resting the opercular movement, especially to shut the gill slit due to its anatomical situation. To these muscles the r.facialis and r.hyoideus are sent both from the ventral of the m.oblongata. At this ventral area of the m.oblongata, there distribute such nuclei of the motor cranial nerves as the fifth, seventh, ninth and tenth and a primary motor center of cerebrum is considered to be formed³⁾⁴⁾. As for the sensory route in eels, the vagus nerve which is the tenth cranial nerve sends out a branchial branch to the gill arches. This nerve connects directly the brain and the gill and so that it may become to be a transmission route to the respiratory center which is considered to be situated in the m.oblongata. In the m.oblongata, there exists also a primary sensory center connected with such sensory cranial nerves as the fifth, seventh, eighth, ninth and tenth³⁾⁴⁾. If considered concisely, it would be possible that these centers cause the above mentioned unilateral opercular movement, accompanying with supposed irregular nervous activities.

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