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Study on Vascular System in the Gills of Some Teleosts by the Resin-replica Method

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Abstract Arterio-arterio and arterio-venous vasculatures in the gills of eel *Anguilla japonica*, carp *Cyprinus carpio*, and yellowtail *Seriola quinqueradiata* were examined by resin-replica method. Their ampullae and anastomotic capillaries of secondary lamellae exhibited species differences in the structural features. In the infusion of resin into the eel gills for 2, 5, and 10 min, the replica of afferent companion vessels, central venous sinus, efferent companion vessel, and afferent artery was produced, but that of the capillaries in secondary lamellae and efferent artery was not recognizable. This finding suggests more abundant blood circulation in the arterio-venous vasculature than in the arterio-arterio one.

Teleostean gills function as respiratory, excretory, and osmoregulatory organs. The vascular system in gills must be closely related to these functions. Recent studies on the vascular system of gills using the resin-replica method have revealed that the teleostean gills have two principal blood pathways, arterio-arterio and arterio-venous vasculatures (Fromm, 1974; Boland and Olson, 1979; Dunel and Laurent, 1980; Farrell, 1980a; Olson, 1981; Laurent, 1982). However, the structural difference among various species in the two vasculatures is still unknown. The present study was performed to reveal the features of the vascular system in some teleostean gills.

Materials and methods

Eight specimens of the eel *Anguilla japonica* (body weight 140–200 g), 6 specimens of the carp *Cyprinus carpio* (body weight 110–230 g), and 3 specimens of the yellowtail *Seriola quinqueradiata* (body weight 970–1210 g) were used in this study. Each fish was anesthetized with ethyl carbamate and placed ventral side up. The aortic bulb was exposed and cannulated. The gills were perfused via the aortic bulb with physiological saline solution, which contained 0.125% sodium heparin and 1.5% ethyl carbamate, for 20–30 min. Methyl methacrylate resin was infused directly into the gills of yellowtail and carp until the resin grew rigid. In gills of the eel, the resin was infused for 2, 5, and 10 min, and also until the resin hardening. The resin was prepared by the method of Murakami (1971). The perfusion pressures of the physiological saline and resin were maintained at 30–40 mmHg. After perfusion, the head was removed and immersed in warm water (50–70°C) for 1 hr, promoting polymerization of the resin, and was then placed in 10–15% NaOH solution (50–60°C). After the resin replica became free from the surrounding tissues, it was rinsed by distilled water and allowed to air dry. The dried replica was coated with gold in an ion sputter (JEOL JFC-1100) and observed with a JEOL JSM T-20 scanning electron microscope.

Results and discussion

Arterio-arterio vasculature. An afferent branchial artery and an efferent branchial artery were observed in a gill arch of all the fish examined. In lateral view, the afferent branchial artery gave off many afferent arteries of primary lamellae at intervals. In dorsal view, the afferent branchial artery was branched into two afferent arteries of primary lamellae. The afferent artery had ampulla at a distance of one third from the base, as reported in catfish, bowfin, and rainbow trout (Fromm, 1974; Boland and Olson, 1979; Olson, 1981). The ampullae of the eel and carp were well developed compared to that of the yellowtail (Figs. 1, 2). Fromm (1974) suggested that the ampulla serves as a branchial heart to pump the blood into the afferent artery during the adduction of the primary lamella. The large ampulla in the eel and carp is probably related to the well developed branchial pump system in these fish.

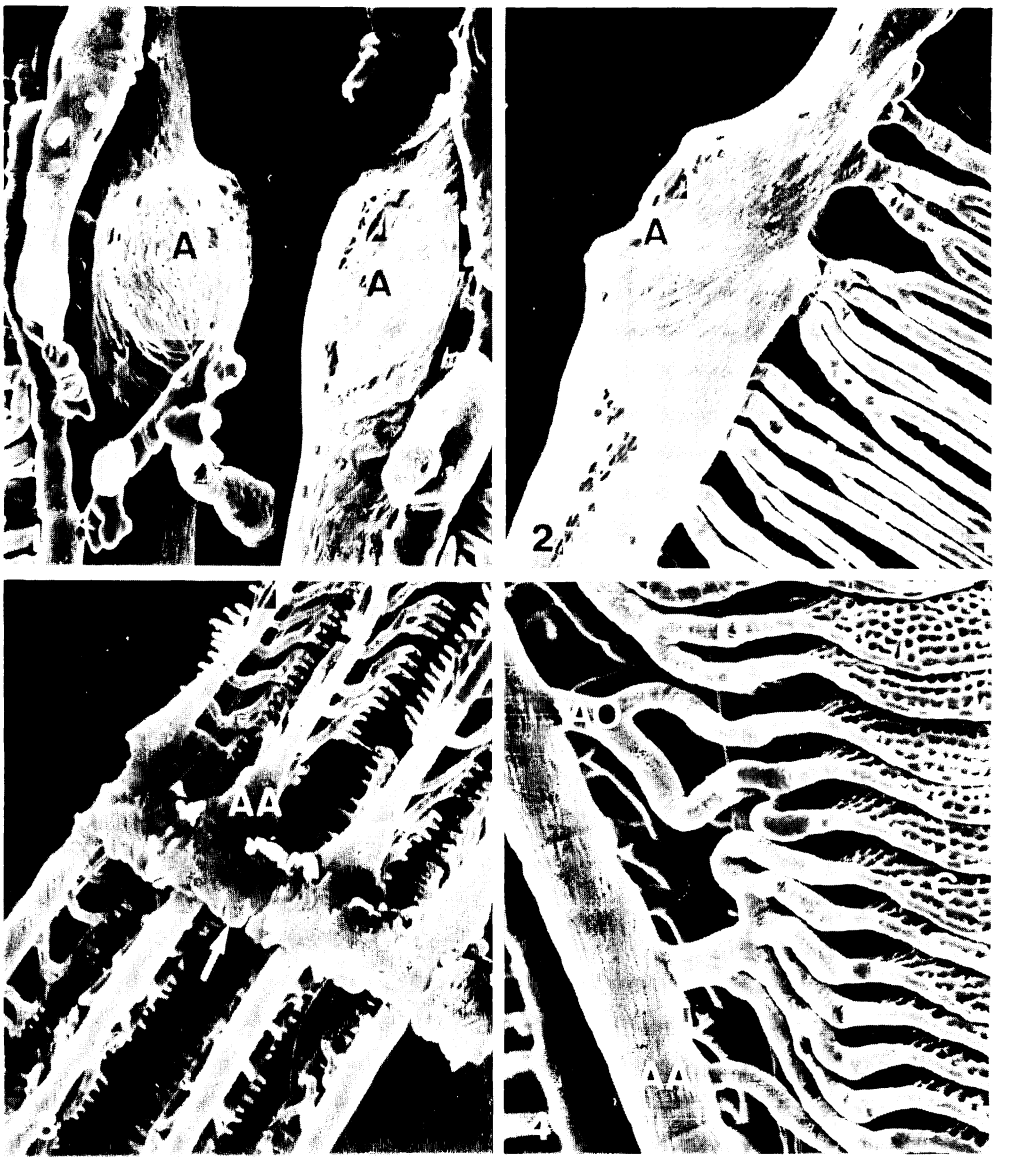

Fig. 1. Ampullae (A) in the afferent arteries of primary lamellae of eel *Anguilla japonica* in dorsal view. They are well developed. ×180.

Fig. 2. Ampulla (A) in the afferent artery of primary lamella of yellowtail *Seriola quinqueradiata* in dorsal view. It is poorly developed in comparison with that of eel. ×108.

Fig. 3. Sinus-like vessel (arrow) joining neighboring afferent arteries (AA) of the primary lamellae of carp *Cyprinus carpio* in lateral view. ×36.

Fig. 4. Afferent arterioles (AO) of the primary lamella of carp in dorsal view. They diverge to connect the capillaries (C) of secondary lamellae. AA exhibits the afferent artery of primary lamellae. ×162.

Only in the carp, the afferent artery connected with the neighboring arteries by a sinus-like vessel (Fig. 3). The same finding was reported by Hughes (1980). In transverse section, the two afferent arterioles branched from the afferent artery of the primary lamella of all fishes examined. In dorsal view, the afferent arteriole diverged to join to several capillaries of the

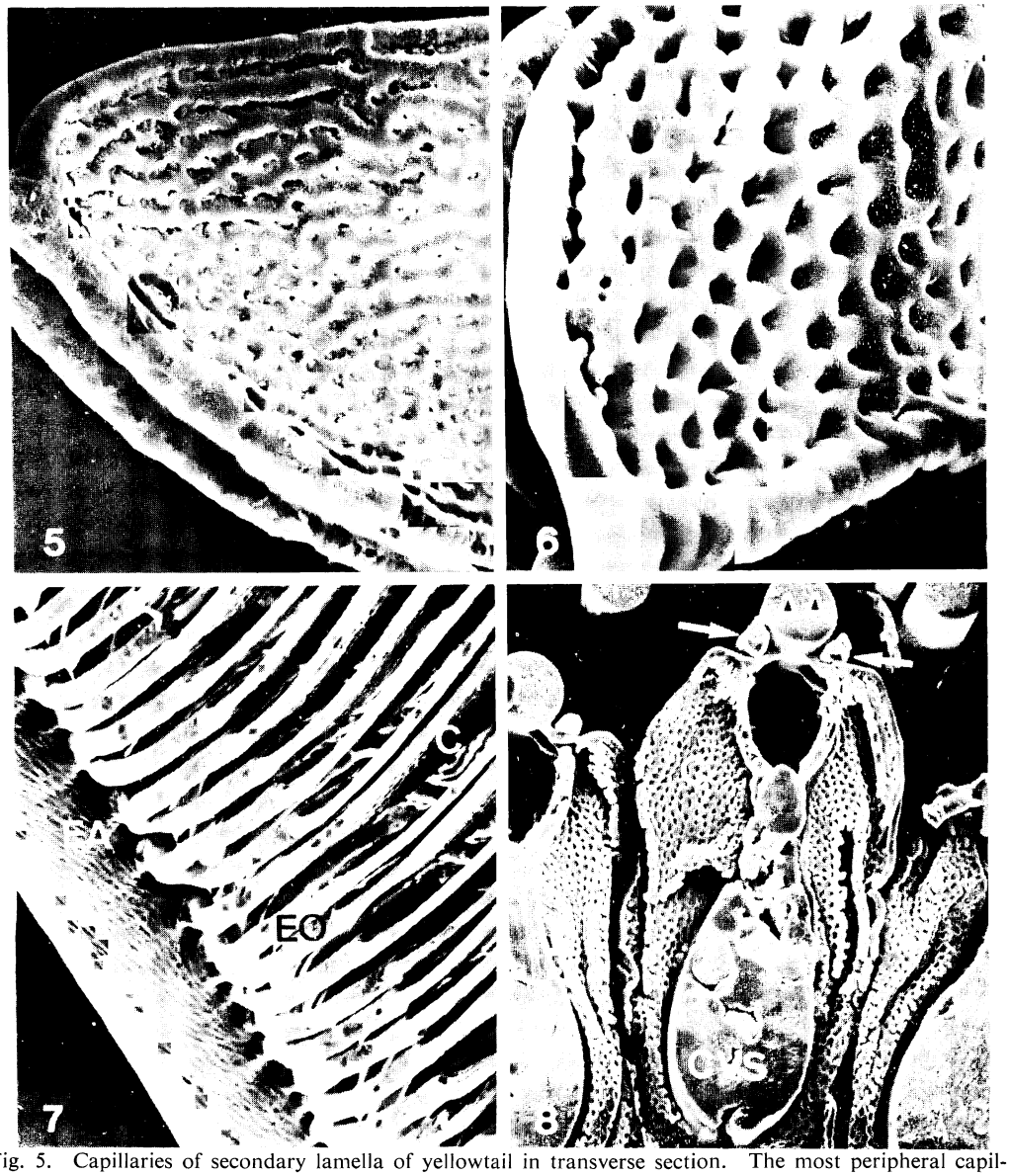

Fig. 5. Capillaries of secondary lamella of yellowtail in transverse section. The most peripheral capillaries are larger in diameter than the other ones. ×360.

Fig. 6. Capillaries of secondary lamella of eel in transverse section. The anastomoses are well developed compared to those of yellowtail. ×720.

Fig. 7. Efferent arterioles (EO) of the primary lamellae of yellowtail in dorsal view. They are scarcely converged. EA and C indicate the efferent artery of primary lamellae and the capillary of secondary lamellae, respectively. ×162.

Fig. 8. Central venous sinus (CVS) and two afferent companion vessels (arrows) of the primary lamella of eel in transverse section. AA and C show the afferent primary lamellae and the capillary of secondary lamellae, respectively. ×14.

secondary lamellae (Fig. 4). The capillaries of the secondary lamella exhibited many anastomoses, which have been observed in many species (Vogel *et al.*, 1976; Boland and Olson, 1979; Farrell, 1980b; Farrell *et al.*, 1980; Olson, 1981). In the present study, the anastomosis was more

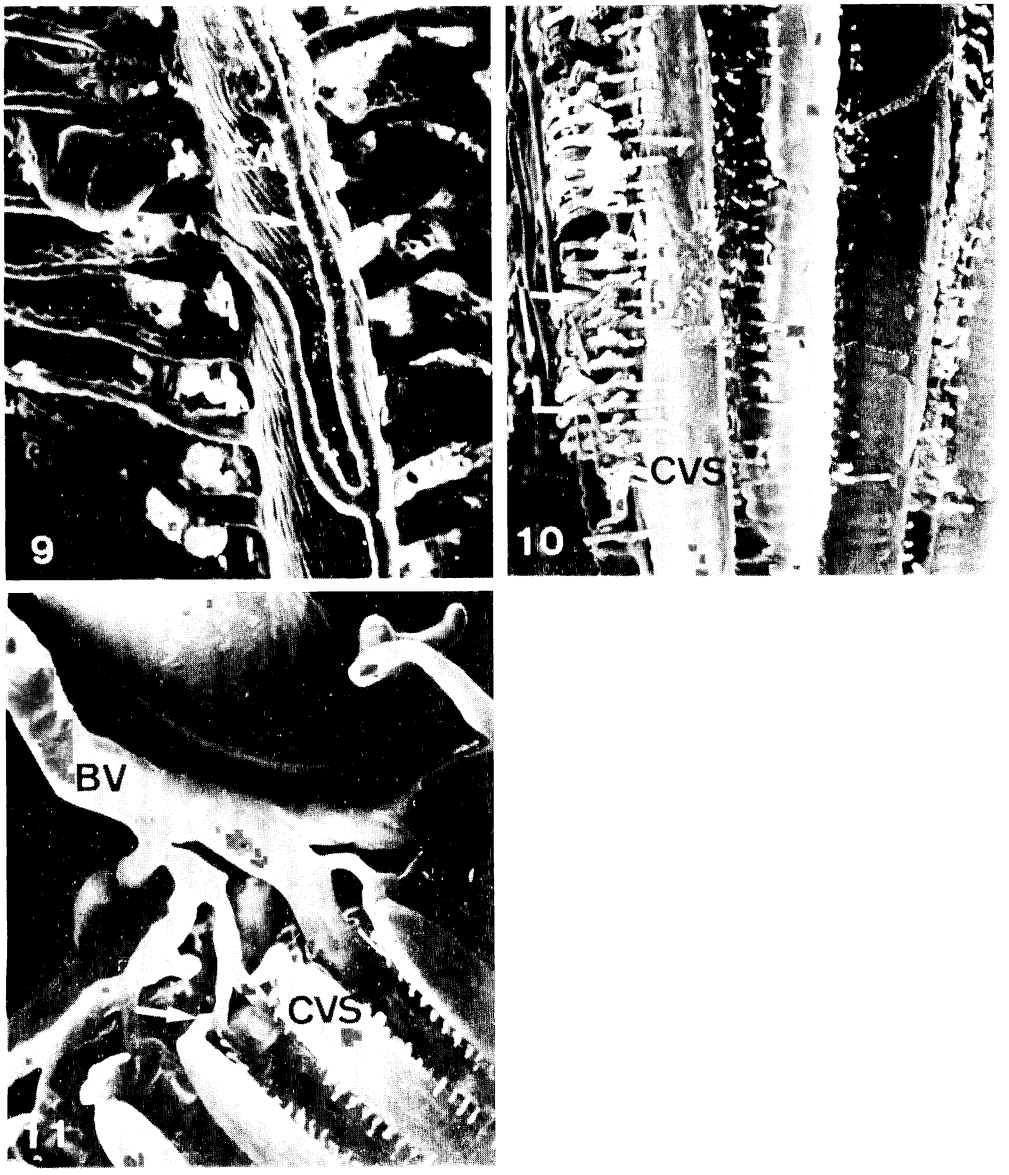

Fig. 9. Efferent companion vessel (arrow) of primary lamella of eel in the lateral view. It joins the efferent artery (EA) and central venous sinus. ×216.

Fig. 10. Vascular system made by the infusion of resin for 10 min. The central venous sinuses (CVS) are perfectly formed, but the capillaries (arrows) of secondary lamellae are hardly produced. ×54.

Fig. 11. Branchial vein (BV) of eel in the infusion of resin for 2 min. The branchial vein gave off many branches. The central venous sinus (CVS) connects the branch at the base (arrow). ×54.

conspicuous in the eel and carp than in the yellowtail (Figs. 5, 6). In all the species examined, the capillaries in the most peripheral region were larger in diameter than those in the other regions. The capillaries of the secondary lamella converged to an efferent arteriole. In dorsal view, the most efferent arterioles join individually an efferent artery of the primary lamella (Fig. 7). The efferent arteries connected with an efferent artery in the gill arch.

Arterio-venous vasculature. In a gill arch of the eel, a branchial vein gave off many branches.

The branch was separated into two afferent companion vessels which ran parallel along the two afferent arteries of different primary lamellae. In transverse sections of the primary lamella, therefore, the two afferent companion vessels were observed near the afferent artery (Fig. 8). The two afferent companion vessels connected with a central venous sinus by their many branches. The central venous sinus showed sinus-like structure and extended the whole length of primary lamella, as seen in ling cod (Farrell, 1980a). In *Perca* and *Salmo*, however, their central venous sinuses are known to exhibit a compartment-like structure (Dunel and Laurent, 1980). An efferent companion vessel ran parallel along the efferent artery of the primary lamella and closed at the both ends. The efferent companion vessel anastomosed frequently with the efferent artery and central venous sinus (Fig. 9). The infusions of resin for 2, 5, and 10 min produced a replica of afferent companion vessels, central venous sinus, afferent artery, afferent arterioles, branchial vein, and afferent branchial artery, but did not form that of capillaries of the secondary lamellae, efferent arterioles, efferent artery, efferent companion vessel, and efferent branchial artery (Fig. 10). Laurent (1982) reported that the central venous sinus communicated with the efferent artery in many teleosts. Vogel *et al.* (1973) described that the blood in central venous sinus came from the efferent artery. In the eel, however, the communication between the efferent artery and central venous sinus is lacking, or even if it is present, the blood circulation through it seems to be scarce, because the replica of efferent artery was not made by the infusion of resin for 2, 5, and 10 min. From the replica of the infusion for 2 min, it appears that the central venous sinus of the eel joins directly to the branchial vein at the base (Fig. 11). The connection between the central sinus and branchial vein was also reported in the European eel (Dunel and Laurent, 1980). In the eel, therefore, the blood in the central venous sinus flows probably from the afferent companion vessel and branchial vein. In addition, the early formation of the central venous sinus in the present observation suggests more abundant blood circulation in the arterio-venous vasculature than the arterio-arterio one, at least, under the anesthetized condition of the eel. In the carp and yellowtail, however, the replica of arterio-venous blood vasculature was scarcely formed, although the resin was infused perfectly into the arterio-arterio blood vasculature. Accordingly, these fish may not have a developed arterio-venous blood vasculature.

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Literature cited

Boland, E. J. and K. R. Olson. 1979. Vascular organization of the catfish gill filament. Cell Tissue Res., 198: 487–500.

Dunel, S. and P. Laurent. 1980. Functional organization of the gill vasculature in different classes of fish. Pages 37–58 *in* B. Lahlou, ed. Epithelial transport in the lower vertebrate. Cambridge University Press, Cambridge.

Farrell, A. P. 1980a. Vascular pathways in the gill of ling cod, *Ophiodon elongatus*. Can. J. Zool., 58: 796–806.

Farrell, A. P. 1980b. Gill morphometrics, vessel dimensions, and vascular resistance in ling cod, *Ophiodon elongatus*. Can. J. Zool., 58: 807–818.

Farrell, A. P., S. S. Sobin, D. J. Randall, and S. Crosby. 1980. Intralamellar blood flow patterns in fish gills. Am. J. Physiol., 239: R428–R436.

Fromm, P. O. 1974. Circulation in trout gills: Presence of "blebs" in afferent filamental vessels. J. Fish. Res. Bd. Can., 31: 1793–1796.

Hughes, G. M. 1980. Functional morphology of fish gills. Pages 15–36 *in* B. Lahlou, ed. Epithelial transport in the lower vertebrate. Cambridge University Press, Cambridge.

Laurent, P. 1982. Structure of vertebrate gills. Pages 25–43 *in* D. F. Houlihan, J. C. Rankin and T. J. Shuttleworth, eds. Gills. Cambridge University Press, Cambridge.

Murakami, T. 1971. Application of the scanning electron microscope to the study of fine distribution of the blood vessles. Arch. Histol. Jap., 32: 445–454.

Olson, K. R. 1981. Morphology and vascular anatomy of the gills of a primitive air-breathing fish, the bowfin (*Amia calva*). Cell Tissue Res., 218: 499–517.

Vogel, W., V. Vogel and H. Kremers. 1973. New aspects of the intrafilamental vascular system in gills of a euryhaline teleost, *Tilapia mossambica*. Z.

Zellforsch., 144: 573–583.
Vogel, W., V. Vogel, and M. Pfautsch. 1976. A scanning and transmission electron microscopic study. Cell Tissue Res., 167: 373–385.

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樹脂鋳型法を用いた真骨魚の鰓血管系の研究

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ブリ，コイ，およびウナギの鰓の血管系を，樹脂鋳型法により検討した．これらの鰓の血管系は，動脈-動脈血管系と動脈-静脈血管系から構成されていた．前者は鰓弓内の入出鰓動脈，一次鰓弁内の入出鰓動脈と入出鰓細動脈，および二次鰓弁内の血管から成り立っていた．コイでは，一次鰓弁の入鰓動脈どうしを連絡する洞様血管が見られた．二次鰓弁内の血管の吻合程度に，魚種差が顕著に認められた．

ウナギの動脈-静脈血管系では，鰓弓内の鰓静脈，一次鰓弁内の入出鰓随伴血管と中央静脈洞が見られた．この動脈-静脈血管系には，動脈-動脈血管系よりも早く樹脂が流入した．コイとブリの動脈-静脈血管系について，十分な観察が行なえなかった．

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