VARIATIONS IN THE SHAPE AND BLOOD SUPPLY OF THE SACCUS VASCULOSUS IN TELEOSTEAN FISHES

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As to the function of the saccus vasculosus, it is well known that two conflicting hypotheses have hitherto been advanced: one as a sensory organ and the other as a secretory one, though at present the latter opinion seems to be more generally accepted.

In the trend of the current research on this organ, attention has been concentrated mainly upon such elements as the coronet cells and choroidal substance occurring in the saccus lumen; on the grounds of their findings some authors have advocated the secretory function (Bargmann, 1954; Dorn, 1954; Kamer *et al.*, 1960). However, in spite of the fact that blood exists as an essential for this much vascularized structure, the literature which deals with blood itself in the saccus vasculosus is very scanty. Yet, it has been accordantly accepted that the changeableness of blood amount is concerned with the function of the saccus vasculosus (Dammerman, 1910; Scharrer, 1948), though any definite characteristics of blood in this organ have not yet been described.

In a previous paper, the author (1962) reported that in *Hime-masu*, *Oncorhynchus nerka*, the shape and blood supply of the saccus vasculosus varied greatly according to specimens. With due regard to the consideration mentioned above,this paper deals with the question whether or not such a variation as found in *Hime-masu* is a substantial phenomenon, which may occur in association with any function of this organ commonly to all the teleostean fishes.

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Materials and Method

The observation of the saccus vasculosus was made on the following nineteen species of teleostean fishes; *Oncorhynchus keta* (WALBAUM) (number of specimens: 16), *Salmo gairdnerii irideus* GIBBONS (115), *Salvelinus miyabei* OSHIMA (70), *Synaphobranchus affinis* GÜNTHER (7), *Arctoscopus japonicus* (STEINDACHNER)

(8), *Lumpenella nigricans* MATSUBARA *et* OCHIAI (3), *Ditrema temmincki* BLEEKER (25), *Fugu vermicularis porphyreus* (TEMMINCK *et* SCHLEGEL) (31), *Sebastolobus macrochir* (GÜNTHER) (11), *Pleurogrammus azonus* JORDAN *et* METZ (6), *Hemilepidotus gilberti* JORDAN *et* STARKS (6), *Tilesina gibbosa* SCHMIDT (4), *Percis japonica* (PALLAS) (3), *Crystallias matsushimae* JORDAN *et* SNYDER (9), *Atheresthes evermanni* JORDAN *et* STARKS (4), *Clidoderma asperrimum* (TEMMINCK *et* SCHLEGEL) (7), *Microstomus achne* (JORDAN *et* STARKS) (4), *Laemonema longipes* SCHMIDT (7) and *Theragra chalcogramma* (PALLAS) (8).

All the fishes employed were of adult form. The individuals of each species were those which had been captured simultaneously from the same habitat. In most cases, the observation was made on the fishes decapitated immediately after they were caught. The materials fixed with formalin solution were also available for the purpose of observation as they retained the original appearance in fresh condition.

To examine the features of this organ under various conditions, a great many specimens of *Salmo irrideus* were employed for the observation; they were sacrificed by means of a variety of methods.

Results of Observation

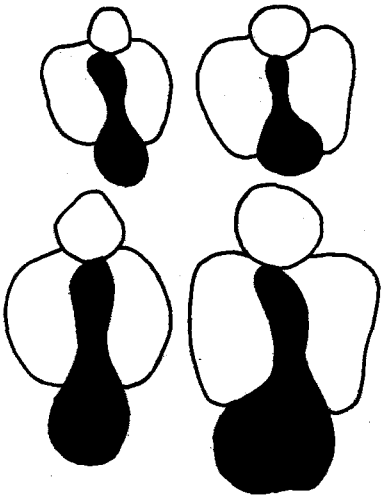
1. Variation in shape

All the fishes used presented their characteristic forms in the saccus vasculosus, respectively. According to their peculiarity in form, the organs were conveniently grouped into the following eight types: rhombic (*Fugu*), cone-shaped (*Ditrema*), ovoidal (*Oncorhynchus*, *Salmo*, *Salvelinus* and *Hemilepidotus*), bell-shaped (*Lumpenella*, *Pleurogrammus*, *Tilesina* and *Theragra*), temple-bell-shaped (*Arctoscopus*), dumbell-shaped (*Sebastolobus*, *Microstomus* and *Laemonema*), round (*Synaphobranchus*, *Percis* and *Crystallias*) and gourd-shaped (*Atheresthes* and *Clidoderma*).

When the shape of the several specimens belonging to the same species was precisely observed, it was recognized that there was variation among them, though the organ's characteristic appearance was retained basically. By ventral observation, the variation of this organ was found to tend in its length and width regardless of the general type of the form of the saccus vasculosus. Among the fishes used here, the species which showed such a high variation were as follows: *Salmo*, *Synaphobranchus*, *Arctoscopus*, *Pleurogrammus*, *Percis*, *Atheresthes* and *Clidoderma*. Variation was rather small, on the other hand, in *Fugu*, *Sebastolobus*, *Microstomus* and *Theragra*.

Some examples of the variation in five species are shown in Text-figure 1 and

Plates I and III. In Figs. 1A-1C (Plate I) of *Arctoscopus*, one can recognize a difference in width according to the specimens, especially at the posterior and anterior parts of the temple-bell-shaped saccus vasculosus. In the case of *Pleurogrammus*, the swelling of the posterior end of the saccus vasculosus appears to vary considerably between the two depicted specimens (Plate I, Figs. 2A and 2B); that is, in the specimen of 2B, the posterior swelling expands bilaterally to a great extent as compared with that of 2A. In the two individuals of *Percis* shown, in contrast with the case of the former species, the variation of shape takes place in the whole portion: that is, in the case of Fig. 3B, the swellings are distinctly found in both the anterior and posterior parts. Text-figure 1 represents examples which showed a high variation of shape of the saccus in *Clidoderma*; as usual, the degree of the swelling of their anterior and posterior parts varies markedly with specimens, as if the various types of gourds had grown up. As to the diverseness of the saccus vasculosus, good examples are found in the case of *Salmo* (Plate III). In Figs. 1 and 2, the sacci are found elongated and thin, whereas that Fig. 3 appears to be ovoidal and relatively voluminous. In such species as *Oncorhynchus* and *Salvelinus*, a considerable variation of this organ was found to occur ubiquitously, though the fundamental form was ovoidal.



Text-figure 1. Showing the various features of the shape of the saccus vasculosus in four specimens of *Clidoderma asperrimum* (TEMMINCK *et* SCHLEGEL)

2. Variation in blood supply

Because of the transparent epithelium of the saccus, the feature of blood supply is easily observable superficially. Blood supply in the saccus vasculosus was found to be different from species to species. Such a difference was observed to be associated with the diverse manner of the distribution of blood. Blood supply in the saccus of *Oncorhynchus*, *Salmo*, *Salvelinus*, *Pleurogrammus*, *Tilesina* and *Theragra* was found to be network-like or streaked. While, in the species such as *Ditrema*, *Fugu* and *Percis*, blood appeared to spread uniformly in the whole area of the saccus. In the other remaining fishes, in addition to such uniform supply, congregation of blood was also observed to exist as spots or dots.

In all the species used, it was also observed that blood supply of the saccus

vasculosus differed by individual. In Plate II, various appearances of bood supply in *Salvelinus* are seen. In Fig. 1, blood is found to exist as dots only in the periphery of the saccus. While as the figures proceed from 2 to 4, blood supply appears to gather increasingly toward the central portion, developing a network-like distribution. In the case of Fig. 4, it is further seen that blood is distributed on the organ's whole area. With regard to the variation of blood supply, the coloured photographs shown in Plate III yield more precise evidence. Fig. 1 is an example showing only a faintly dotted blood supply, while Fig. 2 is superficially a network-like distribution. Furthermore, in the case of Fig. 3, the saccus is seen to be almost completely replete with blood, and besides large sinus-like spots are found in its central portion. It is noticeable that there was not found any sinus-like nor network-like distribution in the saccus of the specimen with little supply of blood, whilst on the other hand either sinus-like or network-like distribution was seen in the organ of the specimen showing large supply of blood. As an example of the striking contrast, the two features of the blood-filled and bloodless sacci in two species are shown in Plate II; the saccus of *Clidoderma* (Fig. 5) is supplied with a large amount of blood, so that it appears to be dark-reddish in colour; while in *Atheresthes* (Fig. 6), it was colourless owing to the scanty supply of blood.

According to the degree of the diversity of blood supply, the fishes examined here could be roughly categorized into three groups. Cited here are the two extreme groups among them, as follows. In *Pleurogrammus*, *Hemilepidotus* and *Percis*, the blood supply was slightly variable; on the other hand, it varied greatly in *Salmo*, *Salvelinus*, *Synaphobranchus*, *Arctoscopus*, *Lumpenella*, *Ditrema* and *Crystallias*.

3. Influence of the sacrificing procedures on the feature of the saccus vasculosus

In order to ascertain whether or not the variation of both shape and blood supply observed is an artifical result caused by any operational disturbance at sacrifice, several procedures for sacrifice were tried in six groups of *Salmo irideus*, each of which consisted of 6-16 specimens.

As the first group, specimens which had been maintained undisturbed from irritable light and noise were taken for the purpose. They were stored in a cistern with stagnant water. Observation during the period of experiment showed that they had rested on the bottom of the cistern except for their early startled behaviour. Confirming the recovery of composure after an hour, quinaldine solution was added with care to the cistern water to anesthetize them under restful condition. Such procedure seemed to be efficacious to anesthetize the fishes without

any distinct excitation. Immediately after asphyxia, the head was severed from the trunk, and then the saccus vasculosus revealed from the head was submitted to observation. In such materials, there was no distinct variation of the blood supply, all the specimens showing a similar feature which was, in most cases, comparable to that of Fig. 2 of Plate III. That is, there was found to exist a moderate supply of blood.

The fishes of the second group were kept moving, but were not threatened by any special disturbance before decapitation. To a strong current induced by bubbling, they had reacted by rheotaxic swimming for three hours. Then they were sacrificed after anesthetized in the same manner as described above. All the sacci vasculosii observed in this group also tended to be similar in colouration. It was difficult to point out any occurrence of variation of blood supply among these specimens.

The fishes belonging to the third group were prepared after they had been subjected to treatment of compulsion. The individuals confined within a cistern were forced to struggle violently for several minutes by disturbing the water strongly with a club. In these affected materials, there were visible various features of blood supply including both of the extreme cases, the bloodfullness and exceeding scantity.

As the fourth group, the specimens of which the heads were destroyed by mechanical force were submitted to observation. As a result of a treatment, in spite of the fact that in most cases the cranial cavity was filled with blood by intercranial hemorrhage, the same observation was made similar to that in the former group; that is, variation in the blood supply was found.

Further, the specimens belonging to the fifth group which has been in agony in oxygen-deficient water for several hours were also submitted to the examination. In such individuals, there was also presented a considerable variation.

A similar variation was found in the last group of the fishes which were released from an artifical hydrostatic high pressure to which they were subjected before sacrifice.

In every observation made on the influence of the sacaificing procedures, the shape of the saccus vasculosus was found to be highly variable according to the specimens, but not due primarily to the method or attendant circumstances in the sacrifice.

Discussion

Although many publications have been presented upon the external morphology of the saccus vasculosus (Lissner, 1923; Uchihashi, 1953; Ohara, 1958; Sato &

Kurotaki, 1958), the papers reported on the variableness of this organ are very little. Zwillenberg (1961) has stated on the individual variation of blood supply in the saccus vasculosus of *Bachforelle*, and the author (1962) has offered a comment on the different shapes and various degree of the blood supply among the individuals of *Hime-masu*, *Oncorhynchus nerka*.

By the present observations made on three hundred and fifty-four specimens of nineteen species, it was confirmed that varied features in shape and blood supply of the succus vasculosus persisted throughout all the species. Judging from the observation that such features of these characteristics were to be seen under both natural and experimental conditions, it may be presumable that the occurrence of such a variation of the organ now under study is actually a phenomenon common to all the teleostean fishes.

As noted in the experiments made on *Salmo irideus*, the variation occurred in the fishes to which various shocks were given, while it was not found in the fishes which were sacrificed without any distress. Taking account of these results, therefore, it is considered that the variation of blood supply is apt to be caused by any disturbance at sacrifice. Needless to say, it is undeniable that all the fishes used might be subjected to various kinds of shock before and after the time they were obtained from their respective habitats until they were sacrificed.

Considering from the manner of blood distribution in the saccus vasculosus, the variation is presumably attributable partly to the quantitative fluctuation of this fluid, which may bring about a change of volume and accordingly shape of the organ. In addition to the opinion stated above, *Turbanorgan* and *elastischer Fasern* which have been demonstrated by Bargmann (1954) to occur in *Dasyatis marinus* seem to be very advantageous structures for participating in giving rise to the variation of the saccus vasculosus concerned.

Ariëns Kappers *et al.* (1936) have described *tractus thalamo-saccularis* (or *tractus prethalamo-saccularis of Sheldon*) as a component in the innervation of the saccus vasculosus, which is stated to originate from dorsal thalamus and to terminate in the blood vessels of the saccus vasculosus. Therefore, if that connection is accepted, the variation is presumed to be under influence of the dorsal thalamus through *the tractus thalamo-saccularis*.

Concerning the distribution of blood in the saccus vasculosus, Dammerman (1910) has mentioned that blood supply is provided by two different processes: one is by *sinus* and the other is *capillary* in nature. In the sacci of three kinds of fishes, Scharrer (1948) has experimentally demonstrated two types of blood vessels, *sinus* and *small empty vessels*. These features were ascertained by Dorn (1954) in *Sebastes norvegicus* and by Hoefke (1955) in several kinds of deep sea fishes.

In the present observations made on *Salmo irideus* and *Salmo miyabei*, the sinus-like and capillary-like distribution of blood were visible externally. It remained unconfirmed whether or not the types of blood supply observed in the present study could be in accordance with *the sinus* and *capillary* or *small empty vessels* systems which have been reported by Dammerman and Scharrer. However, on the basis of the tendency of blood distribution observed, it is presumed that the various features of blood supply are due, at least, to the following processes: that is, poor distribution of blood is mainly concerned with dotty or capillary-like supply, while blood abundance is concerned with ether capillary-like or sinus-like supply. In relation to this subject, Ohara's finding (1958) is of great interest, in which he has noticed that in the arteries toward the saccus vasculosus some valvular apparatuses are found.

The individuals belonging to the same species and also those captured simultaneously from the similar habitat showed various features in blood supply. On the contrary, under some experimental conditions, the saccus was observed to be invariable. These findings suggest that the variableness is derived from some peculiar physiological response to the compulsion applied, being accompanied with changeableness in the amount of blood supplied to the organ. At the same time, it is considered that by revealing the causation and physiological significance of the variableness, some clue for clarifying the definite function of this organ may be afforded.

Summary

Observation was made on the external features of the saccus vasculosus of 354 specimens belonging to 19 species of both marine and fresh-water fishes. The shape and blood supply of the saccus vasculosus were found to be variable from individual to individual throughout all the species examined. Such variations of this organ are liable to be caused by some artifical disturbance at sacrifice, judging from the experimental observations made on *Salmo irideus*.

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Explanation of Plates

PLATE I

Ventral appearances of the saccus vasculosus in three species of fishes. The saccus vasculosus is surrounded by the hypophysis anteriorly and by the lobi inferior bilaterally. Varied features of the shape of the saccus vasculosus are found between the individuals in the following respective species.

Figures 1A–1C: *Arctoscopus japonicus* (STEINDACHNER) ×10

Figures 2A–2B: *Pluerogrammus azonus* JORDAN *et* METZ ×8.3

Figures 3A–3B: *Percis japonica* (PALLAS) ×11

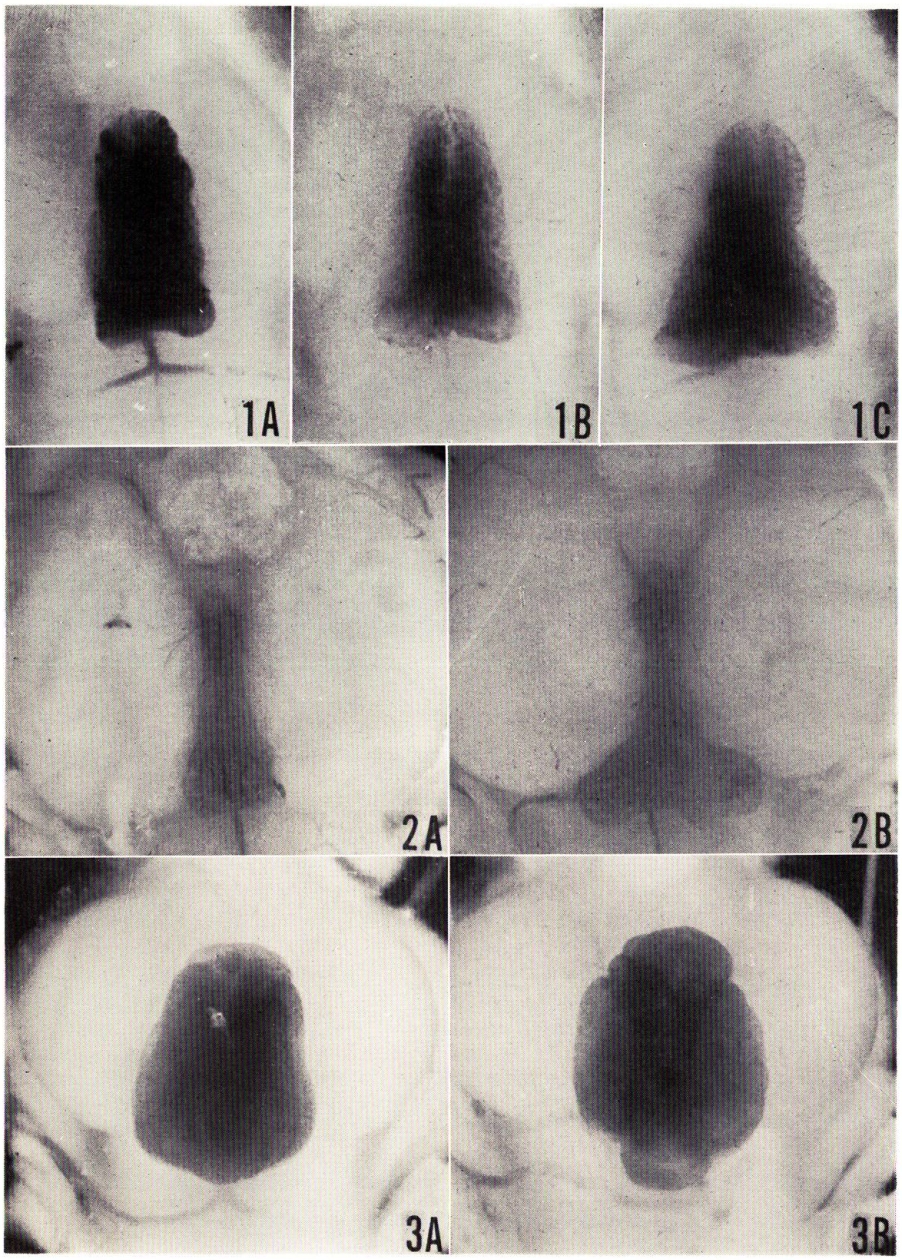

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PLATE II

Figures 1-4: Various features of the saccus vasculosus in *Salvelinus miyabei* OSHIMA (×11-15). As the figures proceed from 1 to 4, the saccus vasculosus becomes occupied by dotty, sinus-like or network-like blood supply.

Figures 5 and 6: Two contrastive features of blood supply of the saccus vasculosus in two species. The saccus is wholly filled with blood in *Clidoderma asperrimum* (TEMMINCK *et* SCHLEGEL) (Fig. 5) (×5.6), while it is not well supplied with blood in *Atheresthes evermanni* JORDAN *et* STARKS (Fig. 6) (×5.1).

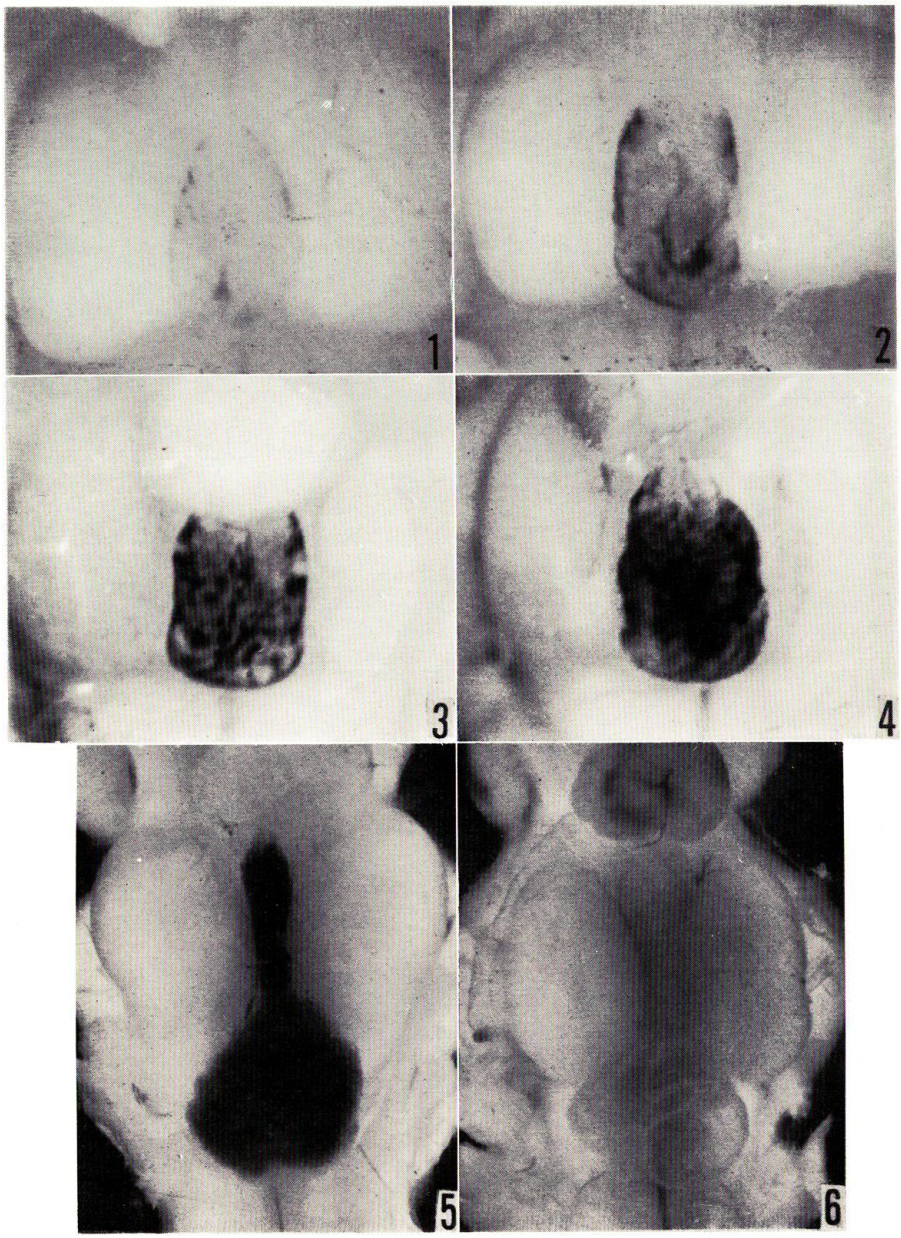

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PLATE III

Three features of the saccus vasculosus in *Salmo gairdnerii irideus* GIBBONS.

Figure 1: Feeble supply of blood, as shown only by small dots. ×8.3

Figure 2: Moderate supply of blood. Network-like distribution is clearly shown. ×8.3

Figure 3: The saccus is completely replete with blood. Several large dots are found in the central portion. ×8.3

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