Japanese Journal of Ichthyology
Vol. XII, nos. 3/6
February 15, 1965

魚 類 学 雑 誌
第12巻 第3/6号
1965年2月15日発行

Cardio-Vascular System of Some Fishes of the Torrential Streams in India. Part I. Heart of *Orienus plagiostomus plagiostomus* and *Botia birdi*

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Introduction

The fishes of the torrential streams of India are accustomed to live in waters rich in oxygen, and their respiratory organs tend to be greatly reduced, since a smaller respiratory area is sufficient to absorb the necessary amount of oxygen (HORA, 1933). Once the organs are reduced, the fish can exist only in waters with a large quantity of oxygen. The waters of the hill streams are so richly oxygenated that most of the fishes have been observed to suspend respiration for a shorter or longer period. The torrential streams are liable either to break up into a series of pools and puddles that may dry up altogether or to become rapid torrents after a single heavy shower. In fishes living in these streams, there is no gradual transition from one type of respiration to the other, as periodic droughts bring about sudden changes in the environmental conditions, and the fish is forced to aerial respiration by storing air in the specially enlarged opercular cavities (HORA, 1933). Aerial respiration provides an example of a fundamental change in the functioning of the main systems of the body and also resultant modifications of the correlated structures. Correlated with the shift from the water-breathing to air-breathing, many great changes have occured in the evolutionary history of the heart, arteries and veins associated with the respiratory region.

DAS and SAXENA (1956, '58) and SAXENA (1958a, b) have discussed the modifications, in the chief blood vessels of the respiratory region, due to the air-breathing habit in *Ophicephalus striatus*, *Clarias batrachus*, *Heteropneustes fossilis* and compared with the water-breathing fishes *Labeo rohita* and *Rita rita*.

On searching through the literature on the subject one cannot fail to be struck by the fact that detailed studies on the circulatory system of the fishes of the torrential streams in general and the heart and the branchial arteries and venous

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system in the respiratory region in particular have been greatly neglected.

The outstanding contributions on the heart of fresh water fishes of India are mainly made by, AWATI and BAL (1934) of the Indian puffers and globe fishes, PRAKASH (1953) of *Heteropneustes fossilis*; KARANDIKAR and THAKUR (1954) of *Sciaenoides brunnaeus* and SINGH (1960) of some fresh water teleosts.

In view of the fact that no account of the heart and circulation of blood in the respiratory region of *Orienus plagiostomus plagiostomus* (HECKEL) (Cyprinidae, Schizothoracinae) and *Botia birdi* CHAUDHURI (Cobitidae, Botiinae) exists, the present authors have worked in detail the external and internal structure of heart of these two fishes to investigate modifications, if any, due to the varied types of respiration forced upon them by the abrupt changes in environment.

The authors wish to express their thanks to Dr. N. Y. KAWAMOTO of Japan for his valuable suggestions in the finalisation of this paper.

Material and methods

The live specimens were procured from Srinagar, Achabal and Palapora (District Anant-nagh, Kashmir). After opening the abdomen and ligaturing of the ventral aorta and the important veins, 5% to 8% formalin solution was injected through the hepatic veins by means of 10 cc. syringe. The whole specimens were then placed in 6% solution of formalin for three to four days for hardening. The heart was then carefully removed for dissection. Dissections on the fresh specimens were also made besides the fixed one's. The drawings were made from the dissections.

The structure of heart

Orienus plagiostomus plagiostomus (HECKEL)

The heart (Fig. 1-4) is enclosed in a thin membraneous sac, pericardium, and lies anterio-dorsally to the pectoral girdle. It consists of sinus venosus, auricle, ventricle and bulbus arteriosus.

The thin walled *sinus venosus* forms the posterio-dorsal part of the heart and is a spacious bilobed chamber—the right portion being bigger than the left. It rests on the ventral base of the oesophagus and is overlapped by the anterior part of the liver lobe. Laterally the sinus receives the ductus Cuvierii and anteriorly the right and left inferior jugular veins. The right inferior jugular vein having slightly larger lumen than the left one, opens near the centre while as the left opens asymmetrically at a little distance away from the centre. The two hepatic veins collecting blood from the right and left liver lobes open posteriorly into the respective sides of the sinus venosus. The sinus venosus opens into the auricle anteriorly through the sinu-auricular aperture.

The *auricle* is very well developed and forms the prominent chamber of the heart having irregular outline. The auricle not only conceals the ventricle dorsally along

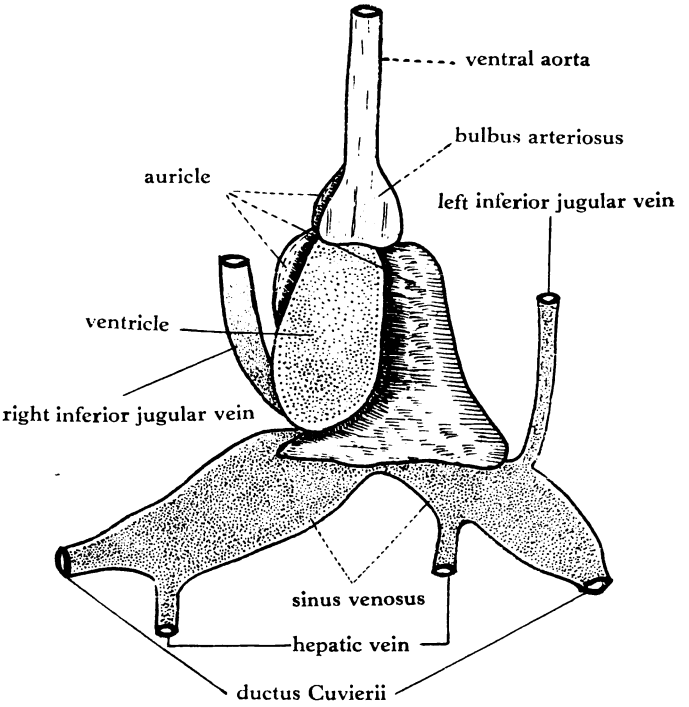

Fig. 1. *O. p. plagiostomus.* Ventral view of the heart.

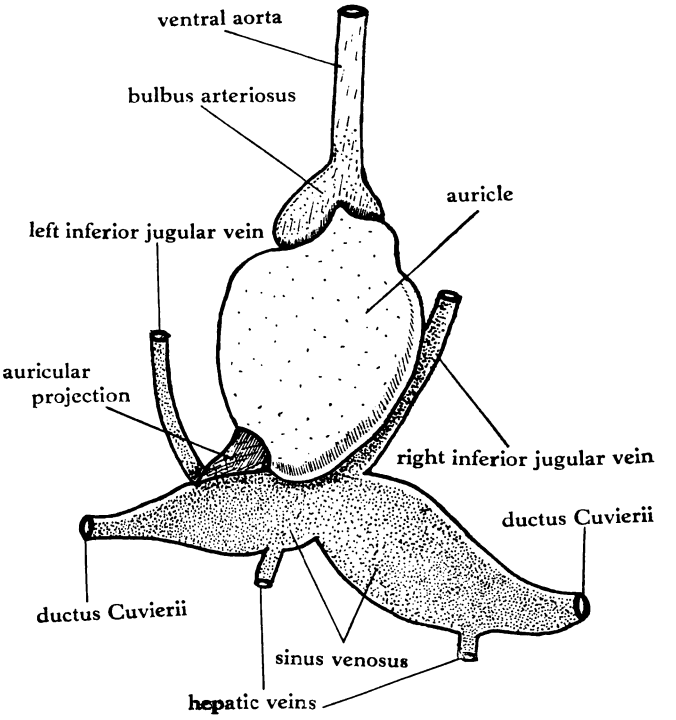

Fig. 2. *O. p. plagiostomus.* Dorsal view of the heart.

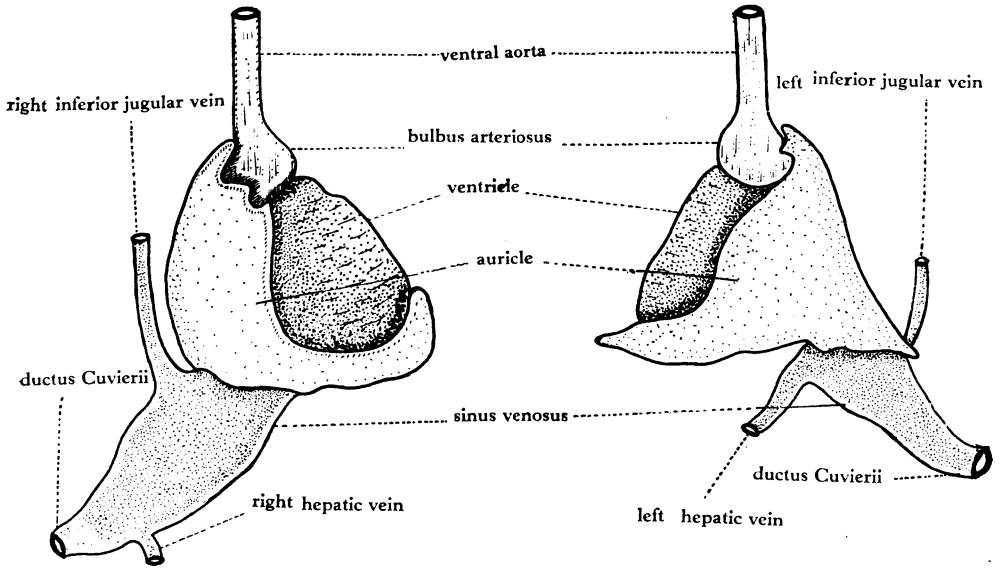

Fig. 4. *O. p. plagiostomns.*
Right lateral view of the heart.

Fig. 3. *O. p. plagiostomus*
Left lateral view of the heart.

with the basal part of the bulbus arteriosus, but partially on the left side also. Posteriorly the auricle is produced in the form of a broad flat sole and it acts as a rest for the ventricle. On the left posterior side it bears a triangular projection which abuts against the sinus venosus. Through the *auriculo-ventricular aperture*, which lies on the left dorsal side of the ventricle, the auricle communicates with the ventricle.

The muscular *ventricle* is laterally compressed and has a large ventral edge. Anteriorly to the ventricle is present a small pear shaped *bulbus arteriosus*, with a swollen basal portion. It has a slight bent towards ventral side and is continuous anteriorly as ventral aorta.

Internally the thin walled sinus venosus (Fig. 5a) is quite smooth. There are no valves present at the openings of the various veins into the sinus venosus. The centrally situated sinu-auricular aperture is guarded by two membraneous *sinu-auricular valves*. The free edges of both these valves are wavy. The lateral ends of the free margins of the dorsal valve are produced and attached to the ventral side of the auricle. The blood from the sinus venosus forces open the two sinu-auricular valves and enters the cavity of the auricle.

The inner lining of the auricle is spongy due to the criss cross arrangement of the muscle fibres and forms a number of smaller pits, very much pronounced in the left part. Small muscle fibres converging around the auriculo-ventricular aperture on the auricular wall help in the flow of the blood from the auricle to the ventricle. The auriculo-ventricular aperture through which the auricle communicates with the ventricle is guarded by four pocket-like valves—the *auriculo-ventricular valves* (Fig.

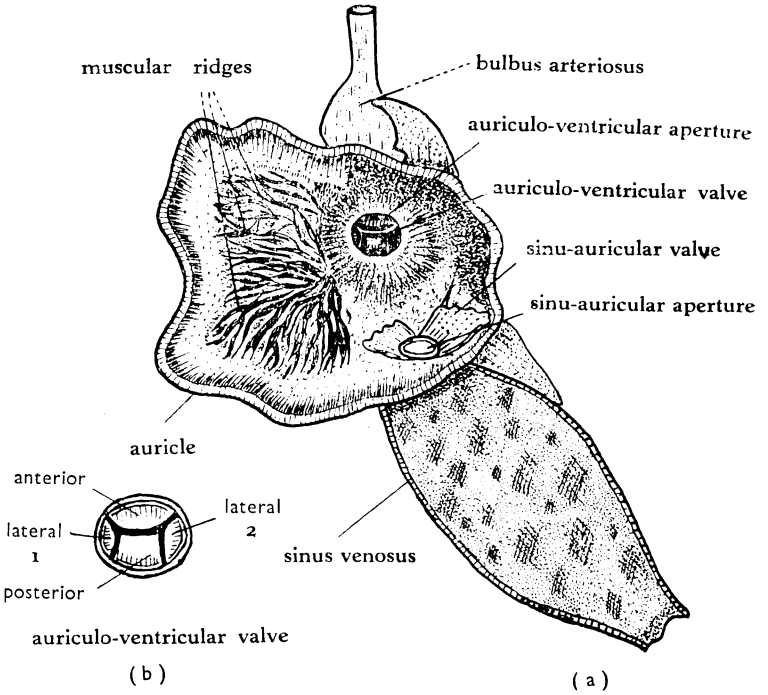

Fig. 5. (a) *O. p. plagiostomus.* Sinus venosus and auricle cut open on the right side. (b) Auriculo-ventricular valves in surface view from the side of the auricle

5b), with their convexities towards the ventricle. All the four valves are well developed, most prominent being the anterior and posterior one. The anterior valve is semicircular in outline while as the posterior one is squarish. When the auricle contracts the blood deflects the sinu-auricular valves towards the sinu-auricular opening to prevent the backward flow of the blood into the sinus venosus and instead forces open the auriculo-ventricular valves apart to enable the flow of blood into the ventricle.

The ventricle (Fig. 6) having thick and compact wall has a reduced lumen due to the extensive musculature. It opens anteriorly into the bulbus arteriosus through a large opening, the *ventriculo-bulbus aperture.* This opening is guarded by two semilunar *ventriculo-bulbus valves* placed dorsoventrally. The convexities of the valves are well within the lumen of the ventricle. On the contraction of the ventricle the blood passes from the ventricle to the bulbus arteriosus, its reflux into the auricle is prevented by the approximation of the free margins of the auriculo-ventricular valves on the ventricular side.

The bulbus arteriosus (Fig. 6) is provided with numerous longitudinal folds all along its inner surface. The backward flow of the blood from the bulbus arteriosus to the ventricle is checked by the ventriculo-bulbus valves, crescentic in form, situated at its base. The blood runs from the bulbus arteriosus into the ventral aorta and then into the afferent arteries.

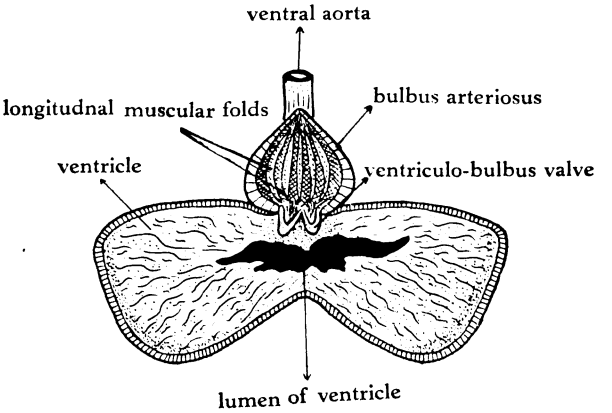

Fig. 6. *O. p. plagiostomus.* Median longitudinal free hand section of the ventricle and bulbus-arteriosus.

Botia birdi CHAUDHURI

The heart (Figs. 7 to 9) is enclosed in a closely fitting pericardium and is placed dorsally to the pectoral girdle. It is more or less bilaterally symmetrical and consists of usual four chambers, sinus venosus, auricle, ventricle and bulbus arteriosus.

The *sinus venosus* is a thin walled chamber on the dorsal side of the auricle. It is slightly bifid having a slight constriction medially on the anterior side. Laterally the sinus venosus receives a pair of ductus Cuvierii and subclavian veins. In *B. birdi* the subclavian veins open into the sinus venosus directly and not in ductus Cuvierii as is the case in most of the teleosts. Anteriorly the sinus venosus receives right inferior jugular vein and a *median pectoralis vein* formed by the union of *right* and *left pectoralis veins* collecting blood from the muscles of the pectoral girdle.

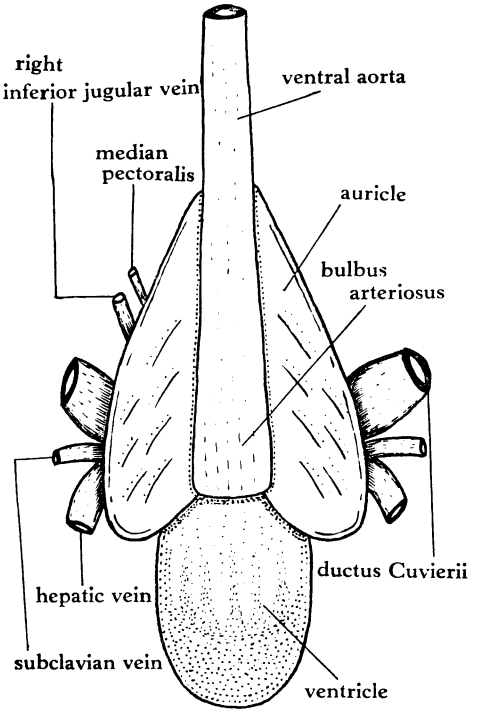

Fig. 7. *Botia birdi.* Ventral view of the heart.

In about fifty per cent of the specimens of *B. birdi* dissected by us, it was observed that the veins originating from the left and median lobes join immediately after emerging from the liver lobes to form a common left hepatic vein which finally opens in the left side of the sinus venosus. While as in other specimens it was seen that the veins emerging out from the median and left

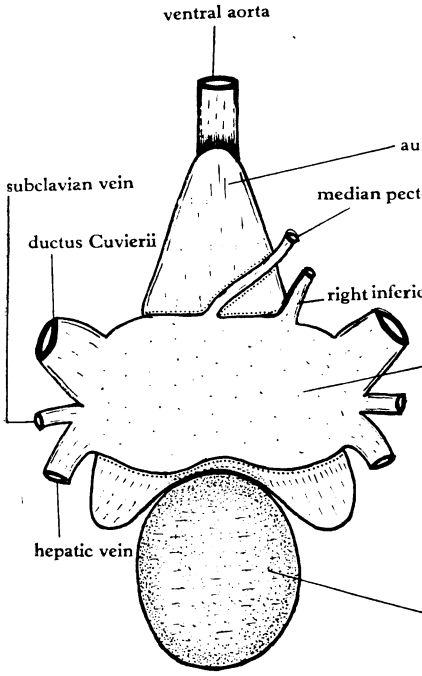

Fig. 8. *Botia birdi*. Dorsal view of the heart.

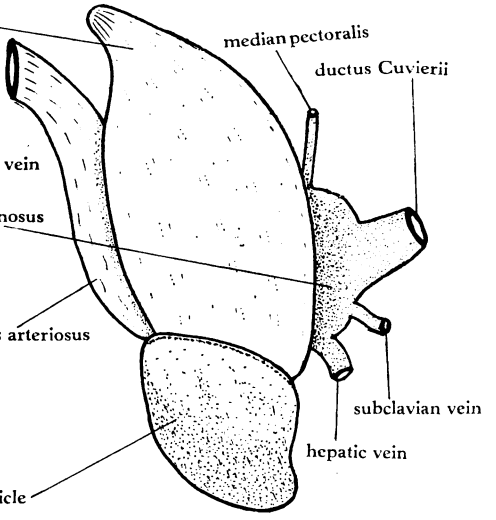

Fig. 9. *Botia birdi*. Left lateral view of the heart.

liver lobes open independently as median and left hepatic veins into the left part of sinus venosus directly. In all the specimens the right hepatic vein from the right liver lobe opens into the right part of the sinus venosus. Thus in *B. birdi there are either two hepatic veins—right and left or three hepalic veins—right, median and left opening into the sinus venosus.*

The *sinu-auricular aperture* through which the sinus venosus opens dorsally into the auricle is slightly on the left side of the median longitudinal line. The *auricle* is triangular in outline having the two apices directed posterio-laterally. The flat right side of the triangular auricle is broader than the left. Ventrally the auricle has a median longitudinal groove, extending anteriorly upto one third of its length, to lodge the tubular bulbus arteriosus. The auricle opens into the ventricle through *auriculo-ventricular* opening which lies anterio-dorsally to the ventricle.

The *ventricle* lies posteriorly to the auricle a little towards the ventral side and about one fourth of its lateral sides are covered by the two lateral apices of the auricle. The ventricle is somewhat oblong ventrally, has a flat circular appearance dorsally and its apex is slightly curved towards ventral side. The ventricle opens anteriorly into the bulbus arteriosus through *ventriculo-bulbus opening* placed ventrally to the auriculo-ventricular opening. The *bulbus arteriosus* is a long tube of the length of auricle having a slight dilated basal portion and is continuous as ventral aorta outside the pericardium.

Internally the thin walled sinus venosus has a smooth surface. The blood which is received by the sinus venosus is pushed into the auricle through the sinu-auricular opening which is guarded by a single well developed membraneous *sinu-auricular valve*. The sinu-auricular valve is attached at one end to the dorsal and right side of the sinu-auricular opening, leaving the left side of the opening open for the inlet of the blood, and at the other end to the right rim of the auriculo-ventricular opening at the base of the auricle. The valve curves towards right side and therefore the basal attachment of the valve is dorso-ventral.

The internal lining of the auricle (Fig. 10) is not smooth but is beset with numerous smaller pits due to the compact criss cross arrangement of the muscle fibres in an irregular fashion. The muscular strands around the auriculo-ventricular

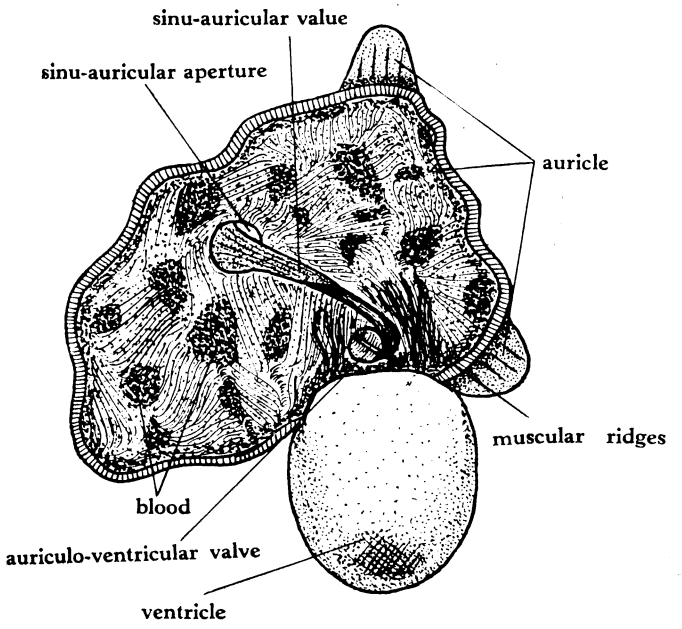

Fig. 10. *Botia birdi.* Auricle cut open on the right side to show its internal structure.

opening in the basal region of the auricle are very well pronounced. The auriculo-ventricular opening is provided with two pocket like, obliquely placed *auriculo-ventricular valves*. When the auricle contracts the sinu-auricular valve gets stretched and thus straightens towards left side closing the sinu-auricular opening completely and thus prevents the backward flow of blood into the sinus venosus. Instead due to the pressure of blood the auriculo-ventricular valves are forced to move apart to allow the flow of the blood into the ventricle.

The ventricle is a thick walled muscular chamber having a number of deep pits to increase the capacity of the ventricle. The lumen is irregular and restricted against the openings of the auriculo-ventricular aperture and ventriculo-bulbus aper-

ture (Figs. 11 and 12). The two definite lumens which are parallel, are separated by ventricular muscles anteriorly and they converge towards each other posteriorly to meet in the centre of the ventricle. The lateral margins of the two auriculo-ventricular valves are connected with the wall of the ventricle by the chordae-tendineae. The ventricle opens into the bulbus arteriosus anteriorly through the *ventriculo-bulbus aperture* guarded by two pocket like *ventriculo-bulbus valves* placed dorso-ventrally well within the base of the bulbus arteriosus. When the ventricle contracts the pressure of the blood acts upon the auriculo-ventricular valves and tends to approximate their free edges so as to close the aperture and thus prevents the backward flow of the blood in the auricle. Instead the ventriculo-bulbus valves are pushed aside due to the pressure of the blood and the flow takes place into the bulbus arteriosus.

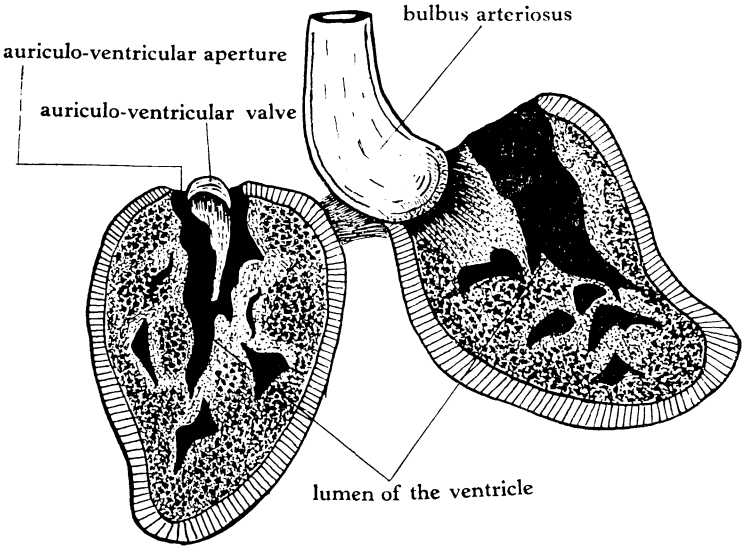

Fig. 11. *Botia birdi.* Longitudinal free hand section of the ventricle through auriculo-ventricular opening.

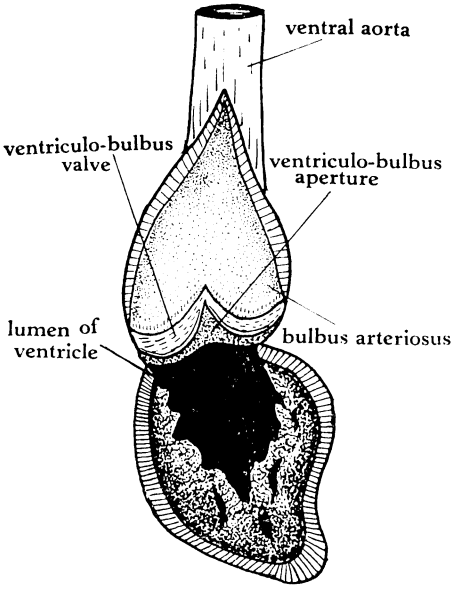

Fig. 12. *Botia birdi.* Longitudinal free hand section of the ventricle passing through the ventriculo-bulbus aperture, along with bulbus arteriosus cut open.

The bulbus arteriosus (Fig. 12) is a wide long tube having thick elastic walls with a smooth inner lining devoid of

longitudinal ridges. When it becomes filled with blood the concavities of the ventriculo-bulbus valves flatten out and close the aperture to prevent the backward flow of blood into the ventricle. The bulbus arteriosus is continuous anteriorly as ventral aorta and there is no definite demarcation between the two regions except that the latter is outside the pericardium and has a uniform diameter of the lumen.

Discussion

To carry out efficiently the cardiac function in a fish, it is necessary that the blood should be collected in posterior chamber and pushed along from the ventricle anteriorly. The relative shift of certain heart chambers extends the auricle forwards, dorsally overlying the ventricle which extends posterio-ventrally. This type of arrangement in the heart has probably two advantages and is chiefly an adaptation to the aquatic environment. The advantages are: a) the blood reaches the ventricle and bulbus arteriosus due to gravity, and b) the thin walls of sinus venosus and auricle provides minimum resistance to the incoming blood.

GOODRICH (1930) pointed out that the teleostean heart shows an extreme stage of specialization peculiar to the group, and not leading to the structure of any of the higher vertebrates, as this conclusion is amply supported by the evidence derived from the other organs. On the other hand SMITH (1960) has stated that the relationship of heart chambers inherited from piscine ancestors are retained in tetrapods.

The heart and the chief blood vessels of the respiratory region in fishes of the torrential streams have not been worked out so far. SAXENA (1958a, b) has definitely established that it is to be excepted that the circulatory system associated with the respiratory region will show modifications with changes in the mode of respiration of the fish.

In *Orienus plagiostomus plagiostomus*, the heart shows no outstanding modification which can be attributed to the varied mode of respiration forced upon the fish due to sudden environmental changes.

In *Botia birdi*, a fish adapted for respiration in the torrential streams and being capable of suspending respiration for short periods, the heart shows many features which have not been observed in any other teleosts.

The sinus venosus in *B. birdi* is dorsal to the auricle and is communicated with it through the dorsal sinu-auricular aperture with a single sinu-auricular valve, whereas generally in teleosts it is posterior in position and the sinu-auricular aperture is provided with a pair of valves.

In *B. birdi* the ventricle is more posterior in position than in any other teleosts and the auricle becomes anterior in position. The auriculo-ventricular opening also shifts in position from dorsal position which is common in teleosts, to anterior position in this fish.

There are two auriculo-ventricular valves in *B. birdi* and four in *O. p. plagio-*

stomus. In most of the teleosts only two auriculo-ventricular valves have been described by GOODRICH (1930), AWATI and BAL (1932), PRAKASH (1953); but SINGH (1960) has reported four valves in a number of fresh water teleosts.

The shift in the position of sinus venosus and sinu-auricular aperture to the dorsal side of the auricle, and the auriculo-ventricular aperture to the anterior side of the ventricle in *B. birdi* is a condition which is found in dipnoans and amphibians, which are able to control their respiratory rate. So it is suggested that the shift in the position of auricle and ventricle may be correlated with the respiratory adaptation of this fish, as this fish is also capable of suspending its respiration for short periods.

Summary

The paper deals with the external and internal structures of the heart of *Orienus plagiostomus plagiostomus* and *Botia birdi*. The heart consists of sinus venosus, auricle, ventricle and bulbus arteriosus as in other teleosts but the position of sinus venosus, sinu-auricular aperture and auriculo-ventricular aperture differs amongst the two forms.

The sinus venosus in *O. p. plagiostomus* receives paired ductus Cuvierii, inferior jugular veins and hepatic veins, while in *B. birdi* it receives paird ductus Cuvierii and subclavian veins a median pectoralis vein, right inferior jugular vein and two or three hepatic veins.

Internally the thin walled sinus venosus is smooth and the auricle is provided with numerous pits due to the criss cross arrangement of muscle fibres in both the fishes. The sinu-auricular aperture is guarded by two sinu-auricular valves in *O. p. plagiostomus* and only by one well developed valve in *B. birdi*. The auriculo-ventricular aperture are four in *O. p. plagiostomus* and only two in *B. birdi*. The ventricle is very much muscular in both fishes but its lumen is comparatively reduced in *O. p. plagiostomus*. There are two semilunar ventriculo-bulbus valve guarding the ventriculo-bulbus opening in both forms. The small pear-shaped bulbus arteriosus of the *O. p. plagiostomus* has longitudinal folds internally, while the inner lining of the long tubular bulbus arteriosus of *B. birdi* is smooth.

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