SPECIAL ARTICLES

THE CIRCULATORY SYSTEM OF THE BRINE SHRIMP[1]

THE brine shrimp, *Artemia salina principalis,* has received extensive biological study in the Hopkins Marine Station and the Stanford University under the direction of Professor E. G. Martin. Due to the fact that it lives in sea-salt brines of extreme saturation, it presents numerous problems of peculiar physiological interest. It seems that to date no one has given especial attention to the anatomy and the physiological manifestations of the circulatory organs and tissues of this animal. Artemia lives on unicellular algae and bacteria and its alimentary tract is not clogged with a great deal of opaque material. The tissues themselves are unusually transparent. It is possible to make out the gross and in fact much of the details of the microscope structure by direct inspection of the animal itself under the compound microscope. The following notes are presented for record.

THE ANATOMY OF THE CIRCULATORY SYSTEM

The plan of circulation in Artemia is the open lacunar system, characteristic of crustaceans. However, the anatomical arrangement is much simpler and very much easier of demonstration than in the higher forms, for example, the decapod crustaceans.

The heart: The heart is a simple longitudinal tube, suspended in the body cavity dorsal to the alimentary tract. It is surrounded by open lacunar spaces, being anchored with more or less firmness by the tissue strands from its walls to the alimentary canal and to the body wall.

The heart tube runs the full length of the animal from the caudal segment to the base of the rostrum. It is an exceedingly thin-walled muscular structure. At the extreme posterior end of the heart is a single opening or slit, the caudal ostium. It is guarded by slight enfolding of the lips which operate as valves. The slit of the opening is dorso-ventral, as is that of all the cardiac ostia.

[1] Professor Ernest G. Martin and Professor Harold Heath, of Stanford University, have made extensive physiological and morphological studies of the west coast Artemia, available in bounteous quantities in Elkhorn slough and adjacent salt beds of the marshes bordering Monterey Bay. This form is a beautiful type for teaching purposes, especially for microscopic demonstration of the open or lacunar plan of circulation. It is remarkably transparent and can be used even under magnifications that reveal cell structure, including muscle striation. It was while preparing material for demonstrating before Dr. Martin's laboratory class in physiology of marine forms that these observations and notes were developed. Since nothing seems available, in the modern literature at least, for the guidance of students of biology these notes are presented. Publication is with Professor Martin's generous consent.

There are bilaterally symmetrical pairs of ostia, from fourteen to fifteen in number, apparently segmental in arrangement, distributed along the sides of the heart tube from the posterior end for two thirds or more of its length. These ostia are guarded by valves as in the case of the terminal or caudal ostium. The walls of the valves are so thin that it requires a medium magnification (x 200–250) to bring them into clearest vision.

There are no ostia along the extreme anterior portion of the cardiac tube. The anterior end of the heart opens freely into sinuses or lacunae at the base of the antennae and eye stalks and adjacent head region. There are no internal cardiac valves.

The lacunar system: There are no blood vessels (Gerstæcker) other than the heart tube, in Artemia. There are certain channels that are well marked and fairly definite. No linings or definite walls of the vascular type were observed. The body cavity and lacunae of the body and appendages are filled with a clear fluid that contains in suspension many nucleated corpuscles. The movements of these corpuscles enables one to follow the outlines of the spaces with remarkable ease. These channels and spaces of the body can be followed out through the appendages—the eye stalks, base of the antennae, limbs, etc. The outlines of the body cavity spaces are much more definite toward the posterior part of the body.

PHYSIOLOGY OF THE CIRCULATION IN ARTEMIA

The body fluid or blood of Artemia is kept in circulation by the interaction of two mechanical factors. First, the pumping of the heart tube and, second, the general body movements, primarily of the appendages.

The contraction of the heart: The straight heart tube contracts rhythmically, with a rapid wave-like movement. The contraction begins at the posterior end and runs in a peristaltic wave toward and over the anterior end. The rhythm at laboratory temperatures and in sea water varies about 125 per minute. The succeeding contraction begins before the preceding one has passed off the tube. The movements of the wafer-thin valves that guard the vertical slits of the pairs of ostia furnish an index of the relative pressures in different parts of the tube and in the adjacent lacunar spaces. This observation is further facilitated by the passing of white corpuscles. Very seldom does one observe corpuscles to move outward through an ostium, or to repass the valves during a peristaltic contraction wave. Occasionally there is a well-marked back and forth movement in the spaces adjacent to the ostia. Even in such instances one could usually observe that the corpuscles had not quite passed the portal of the valve before the peristaltic wave came along.

Since there are no valves in the anterior part of the tube and the anterior end is unguarded and freely open into the heart sinuses, it would seem that the forward movement of the blood is the result of differential pressures produced by the passing of peristaltic waves as supported by the valves guarding the ostia. In confirmation of this is the easily observed fact of the pouring in of the blood stream through the ostia during the relaxation stages of the heart tube.

At the wide open anterior end of the cardiac tube the blood flow shows a rhythmic slight backward movement followed by a more pronounced onward rush synchronous with the heart beat. The phenomenon is more clearly observed when accentuated by pressure of the cover slip on an animal mounted in a culture slide.

The blood flow in the body lacunar spaces: The flow in the body cavity and in the appendages is broadly speaking from the cephalic toward the caudal region. But the rate of flow from time to time in particular regions, and to no small extent the direction of flow, varies with the body movements. When the plane of focus is varied between that of the body cavity in the mid-length at the superior surface of the alimentary canal and the slightly deeper plane, blood corpuscles are seen moving along the sides and surface of the gut in a general caudal direction. If a contraction of the digestive tube occurs, then broad fields of corpuscles sweep across the canal surface from one side to the other, now in one direction and now the other.

In the caudal third of the body-cavity well-marked streams of blood are to be observed on each side of the canal that sweep down into the tail lymph spaces and swirl about to enter the lateral as well as the caudal or terminal ostium of the heart. The lateral ostia are clearly marked by entering streams of blood from these two main currents. One can think of these lacunae as pericardial in type, in the sense in which the term is used in the higher crustacean types—crabs, crayfishes, etc.

The blood flow in the appendages: The outward flow of body fluid into the appendages is in more definite channels, and more rapid and constant, especially in the more anterior pairs—the eye stalks, the antennae and the first two or three pairs of legs. In the leg segments, especially in the so-called respiratory plates, the lacunae often form quite definite capillary-like patterns. The blood can be observed to flow out in the larger of these, usually to one side, and back in adjacent and smaller spaces, sometimes on the opposite side of the appendage. However, in the peripheral regions the flow is often reversed, and varies greatly in speed from time to time in particular spaces. Observing different regions at the same time, the variation in rate of flow in symmetrical appendages is a striking fact. This fact seems largely to depend on the mechanical influence of general body movements.

The activity of the heart, the movements of the respiratory appendages and of the alimentary canal all furnish splendid physiological indexes for interpreting the immediate physiological effects of variations in environmental conditions.

CHAS. W. GREENE

HOPKINS MARINE STATION OF
STANFORD UNIVERSITY,
PACIFIC GROVE, CALIFORNIA

THE REPRODUCTIVE CYCLE OF THE CHARACEAE

A SINGLE tuft of a very interesting species of *Nitella* (as yet undescribed) was found by me several years ago in a pool on the grounds of this university, and the same species has recently been located in a greater quantity elsewhere in this vicinity. Its most striking peculiarity is that the antheridium is divided into longitudinal quadrants only. I had never felt satisfied with my knowledge of this organ and the mode of its development, and its much greater simplicity in this new species led me to undertake its careful study, as well as that of the oogonium.

I had made some substantial progress in this when my work was interrupted for a few years by circumstances that need not be detailed here. I took it up again last summer and have this year devoted my entire time to it for nearly three months. I have now begun upon a comparative study of a member of the same genus in which the antheridium has the classical division into octants. It is my purpose to follow this with a similar study of species of at least two of the other genera that compose the family of the Characeae. I hope to be able in the near future to publish a detailed account of my results. In the meantime I feel that some of those that I have already obtained will be of interest as throwing light upon this peculiarly aberrant group of plants. They refer, of course, to this particular species.

The first of these is the fact that the plant-body, with its very definite structure, is in the diploid phase (the "2x-generation"), differing in that important respect from any of the Green Algae (as far as we know).

The second, and most important, is the location of the reduction divisions in both the oogonium and the antheridium. This takes place in the apical cell, at a very early stage, in the primordium of each organ. This cell, in the oogonium, soon becomes elongated transversely and assumes an ovoid shape in becoming