We have shown that a relation also exists between the number and distribution of neurons with NFD and performance in the acquisition task (6). Histological examination for the regional distribution of NFD in animals whose cortical aluminum concentrations are shown in Fig. 1 suggests a relation between the concentration of aluminum and the density of NFD. Animal 32 (Table 1 and Fig. 1) had extensive NFD only in regions adjacent to the site of injection, and no NFD was noted in the cerebral cortex. Animal 21 had extensive NFD in the entorhinal cortex, the hippocampus, and scattered lesions in neocortex. Animal 27 had extensive NFD in all neocortical regions, entorhinal cortex, hippocampus, and brainstem. This animal had an average frontal and cortical concentration of aluminum of 17.5 μg and the slowest acquisition rate of 42 trials to criterion. Animal 31 had no NFD in the cortex of the occipital pole, but large numbers of lesions in cortex of the frontal pole and entorhinal region. Aluminum concentrations were 26.1 and 1.2 μg/g in frontal and occipital poles, respectively. Although effects of aluminum on brain structures other than cerebral cortex may alter acquisition performance, these data suggest that cortical tissue concentrations above 12 μg/g (dry weight) in the cat are associated with extensive NFD and profound alterations in higher nervous functions.

In brains of humans with Alzheimer's disease (Table 2), aluminum concentrations approach 12 μg/g in some regions. Biopsy material from the brains of patients H.M. and L.T. contained 11.5 and 9.9 μg/g (dry weight) of aluminum, respectively. The usual light and electron microscopic configuration of human NFD (4) was present in tissue from cortical regions near the assay site. The aluminum content of the surgical perfusion media to which the biopsy material might have been exposed in patient L.T. contained 0.06 μg/ml. The cerebral spinal fluid of this patient contained 0.12 μg/ml. When the patient (L.T.) died several months later, postmortem examination of the brain confirmed increased aluminum concentration, and 9.4 and 6.3 μg/g were found in several frontal and temporal cortical regions. A wide range of concentrations were encountered; several samples had values between 3.0 and 5.4 μg/g and some were in the normal range of 0.7 to 2.6 μg/g. Patient C.H., aged 88, had a particularly high density of NFD in one parahippocampal gyrus. In the contralateral parahippocampal gyrus, 9.7 μg/g of aluminum was present. In an atrophic gyrus of frontal lobe a value of 4.8 μg/g was noted, and in some regions of the occipital cortex only 1.4 μg/g. Patient A.S., aged 85, had low concentrations of aluminum in most cortical regions, but the parahippocampal gyrus contained 8.4 μg/g.

Concentrations of aluminum in normal human brains are also shown in Table 2. Patient N.N., aged 64, died suddenly from myocardial infarction and had no evidence of intellectual impairment. The mean value of aluminum in that brain was 1.1 μg/g, with a range of 0.23 to 2.7 μg/g (dry weight). Patients R.A. and L.M. had a range of 2.5 to 0.4 μg/g (dry weight). These normal values correspond to those reported by McLaughlin *et al.* (1) in which spectrographic analysis of eight normal brains revealed less than 3 μg/g (dry weight).

A characteristic pathological finding in Alzheimer's disease is the patchy distribution of NFD. A similar distribution for the pathogenic agent might be expected, and the variation in aluminum concentration in cortical regions is noteworthy. The density of NFD in the experimental model is often very much higher than that encountered in Alzheimer's disease. Nevertheless, the surprisingly high tissue concentration of 9 to 11 μg/g in some regions of brain in Alzheimer's disease, compared to the average values of 14 μg/g in cat brain with experimental NFD, suggests that aluminum may be a neurotoxic factor in the human disease. However, the atomic absorption method measures the total amount of aluminum, and the possibility that this element is bound in a nontoxic form cannot be excluded at this time. It will be necessary to identify the tissue binding sites in both experimental NFD and Alzheimer's disease to further establish the role of aluminum in the pathogenesis of the disease. In addition, not all of the pathological changes in Alzheimer's disease are readily explained by these findings and our study does not exclude the possibility of other etiological factors.

D. R. CRAPPER
Departments of Physiology and *Medicine, University of Toronto, Toronto 5, Ontario, Canada*
S. S. KRISHNAN
Departments of Physiology and *Medicine, University of Toronto,* and *Center for Forensic Sciences, Toronto*
A. J. DALTON
Department of Psychology, Mental Retardation Center, Toronto

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Heart Activity and High-Pressure Circulation in Cirripedia

Abstract. *Pulsating hemolymph pressures of remarkable magnitude for invertebrates are prevalent in the Pacific gooseneck barnacle. Mean pressures of 250 centimeters of water are common with pulse pressures up to 70 centimeters of water. The pulsations are distinctly rhythmical and the pulsation rate is highly temperature-dependent. The results strongly suggest that in cirripeds hemolymph is circulated by muscular contractions of a functional heart.*

The most familiar members of the crustacean order Cirripedia are the acorn barnacles and the gooseneck barnacles. Hemolymph circulation in Cirripedia is not well understood and ideas concerning its occurrence are controversial. Present views include the notions that a circulatory system is completely lacking (*1*), that a unidirectional flow of hemolymph is set up by contractions of the body musculature (*2, 3*), and that an organized

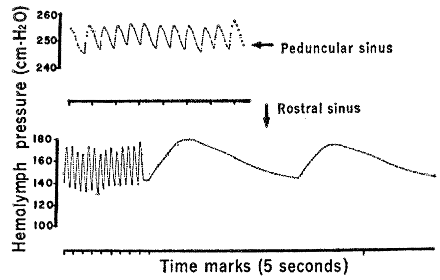

Fig. 1. Pressure pulses from various recording sites in *Pollicipes polymerus* at a body temperature of 18°C.

flow of hemolymph is accomplished by rhythmical contractions of a special blood pump (*4*). These three divergent views are based solely upon morphological studies, but so far there have been no studies employing physiological methods to elucidate the dynamics of circulation in Cirripedia.

Rhythmical impedance variations synchronous with beating of cirri have been demonstrated in the barnacle *Balanus balanoides* (*5*). This rhythmicity may reflect a muscular pump engaged in hemolymph circulation, since the activity persists after the cirri are retracted.

In the Pacific gooseneck barnacle, *Pollicipes polymerus*, rhythmical beating of cirri does not occur. The absence of this potentially confusing event makes the animal especially suited for study of circulatory pumping activity. The present study employs sensitive strain gauge electromanometers for direct, continuous recordings of hemolymph pressure in intact, unrestrained specimens of *P. polymerus*.

Pollicipes polymerus is a sessile form adapted to intertidal life on highly exposed rocky shores (*6*). It occurs commonly along the Pacific coast of North America, attaining a total length of 10 to 15 cm and a weight of 35 to 40 g. A gooseneck barnacle is morphologically divided into a stout muscular stalk, the peduncle, by which the animal is attached to the substratum, and an upper plate-covered mantle, the capitulum, which encloses the cirri-bearing body. Animals collected for study were attached to mussel shells; they were kept in running seawater at a temperature and salinity identical to that in the natural habitat. Short (15-cm) polyethylene catheters were inserted into the body sinuses with the tip of a hypodermic needle, attached to the front end of the catheter, making the actual puncture. Hemolymph pressure was then recorded with Statham pressure transducers and a Beckman oscillograph.

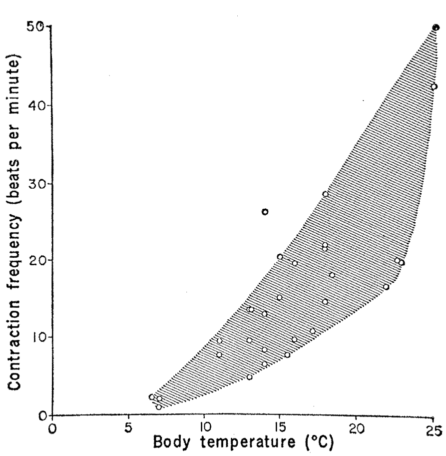

Fig. 2. Relation between body temperature and contraction frequency of the contractile pumping mechanism in *Pollicipes polymerus*.

Recordings of hemolymph pressure from locations in the peduncle as well as from the capitulum gave uniformly high pressures ranging from 110 to 350 cm-H_2O in different animals (Table 1). The hemolymph pressures were always pulsatile and distinctly rhythmical although pulse amplitude and frequency showed considerable individual variation. When animals were left undisturbed, both pulse pressure and absolute pressure (mean of systolic and diastolic pressures) remained stable for as long as 3½ hours. Disturbing the animals resulted invariably in contraction and shortening of the peduncle, and the absolute pressure increased up to 500 cm-H_2O. No correlation was found between hemolymph pressure and size of the animals (range, 3 to 35 g), nor did the recording site (peduncular vessel, peduncular sinus, or capitulum) appear to influence the level of the pressure. Changes in body temperature, however, did influence the pressure level (Table 1). At 18° to 22°C the absolute pressure decreased to about 70 percent of the pressure prevailing at the lower temperatures (7° to 17°C).

The amplitude of the pulsations varied with the recording site, being larger in the capitulum than in the peduncle. In the capitulum, amplitudes ranged from 15 to 70 cm-H_2O. The largest pulse pressures were obtained when the catheter was inserted through the adductor scutorum muscle with the tip located in the rostral sinus (Fig. 1). Pulse pressures from the peduncle were much lower, commonly 8 to 10 cm-H_2O but ranging from 3 to 20 cm-H_2O (Fig. 1). The form of the pressure wave is strikingly similar to that of most vertebrate arterial pressure pulses. The pressure rise (dp/dt) increases abruptly during the contraction phase, whereas the runoff slope during the relaxation phase is less steep, reflecting the compliance and capacity of the outflow system.

Table 1. Hemolymph pressure (mean of systolic and diastolic pressures) in *Pollicipes polymerus* at various body temperatures. The pressures are given as mean values ± standard error of the mean above ranges which are in parentheses.

Body temperature (°C)	Individuals (No.)	Hemolymph pressure (cm-H_2O)
7 to 12	8	250 ± 21 (150 to 350)
13 to 17	10	245 ± 22 (130 to 350)
18 to 22	12	175 ± 13 (110 to 250)

The contraction frequency increased sharply with body temperature (Fig. 2); it has a Q_{10} of 5 to 10 in the temperature interval from 7° to 15°C, and a Q_{10} of 2 to 3 in the interval from 15° to 25°C. The pulse amplitude, however, was independent of temperature.

The contraction phase (systole) and relaxation phase (diastole) of the pres-

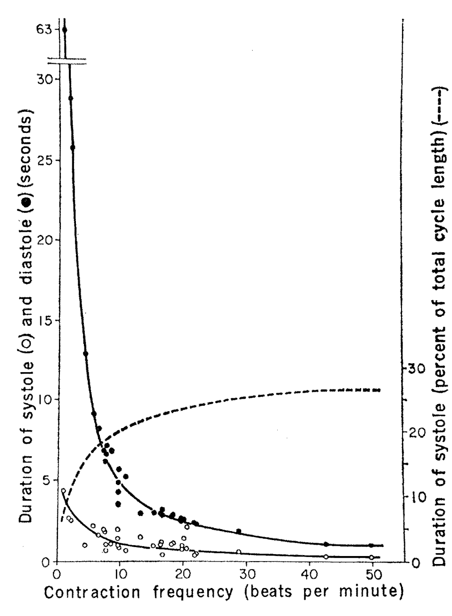

Fig. 3. Duration of systole and diastole of the contractile pumping mechanism in *Pollicipes polymerus* as a function of contraction frequency.

sure pulses were analyzed at different contraction frequencies (Fig. 3). The duration of the systole varied much less with the contraction rate than did duration of the diastole. For both systole and diastole the greatest dependency was exhibited at frequencies below ten beats per minute. Thus the change in contraction frequency of the contractile pumping mechanism depends more closely on a changing duration of the diastole than on a changing duration of the systole, a feature that is basic to all circulatory pumps, invertebrate or vertebrate. The broken line (Fig. 3) shows that the relative duration of systole is only slightly dependent on contraction frequency except at the lowest values. Systole thus makes up a rather constant proportion of the cycle length (20 to 27 percent) at frequencies between 10 and 50 beats per minute.

Rhythmical hemolymph pressures of the magnitude recorded from *P. polymerus* are highly unusual among invertebrates. Indeed, rhythmical contractions of this magnitude involved with circulation and not with burrowing or other locomotory events are unique. Crustaceans generally show hemolymph pressures less than 15 cm-H_2O (*7*). In the large barnacle *Balanus nubilus*, however, internal pressures reach values matching those presently recorded when the animal responds to disturbance by strong muscular contraction (*8*).

The pulsatile pressure in *Pollicipes polymerus* no doubt reflects the contractions of a muscular pumping mechanism, propelling hemolymph unidirectionally. The large pulse pressures suggest circulation in a system of high peripheral resistance. An anatomical basis for such a highly organized circulation in *P. polymerus* has recently been described (*3*).

The identity and location of the contractile pump, however, remains conjectural. The finding of large pressure amplitudes in the rostral sinus supports Cannon's view (*4*) that the rostral sinus, with its valves and encircling muscles, functions as the main propulsive organ in gooseneck barnacles. Further studies are needed to learn whether functional hearts are widespread among cirripeds and other groups of animals that lack obvious tubelike or chambered hearts.

H. J. FYHN*
J. A. PETERSEN†
K. JOHANSEN‡

Friday Harbor Laboratories,
University of Washington,
Friday Harbor 98250

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* Permanent address: Institute of Zoophysiology, University of Oslo, Oslo 3, Norway. Present address: Duke University Marine Laboratory, Beaufort, North Carolina 28516.
† Present address: Department of Comparative Physiology, Institute of Biosciences, University of São Paulo, São Paulo, Brazil.
‡ Present address: Department of Zoophysiology, University of Aarhus, 8000 Aarhus, Denmark.

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Photosynthesis and Atmospheric Oxygen

The significance of photosynthesis as a source of atmospheric oxygen was questioned by Van Valen (*1*) who pointed out that the oxygen separated from carbon dioxide by a plant in photosynthesis is necessarily stoichiometrically equivalent to the carbon fixed in the plant cells and is therefore just sufficient to balance the plant's respiration and to oxidize the plant after death, processes in which the carbon recombines with oxygen to form carbon dioxide. From this reasoning he concludes that plants cannot produce a net change in oxidation and that the origin of atmospheric oxygen is unknown. Similar statements have been made by others (*2*).

One important factor is overlooked in this line of reasoning: The rate of cycling or the residence time of carbon in the reduced, "organic" part of the carbon cycle. As long as the carbon is reduced, its equivalent oxygen can remain elsewhere in the system, for example in the atmosphere. Van Valen considers the short life-span of plants and animals (maximum of a few hundred years), but, while he mentions the organic carbon buried in sediments, he appreciates neither its mass nor the time that it remains isolated from oxygen in the atmosphere.

Rubey estimated the mass of carbon now contained as organic debris in sedimentary rocks, dominantly shales, as 68×10^{20} g (*3*). This mass of carbon is the stoichiometric equivalent of 182×10^{20} g of oxygen. The total oxygen in the atmosphere is 11.8×10^{20} g (*4*). Thus the oxygen in the atmosphere can be more than accounted for by carbon fixation by plants in photosynthesis. The balance of the oxygen liberated in photosynthesis, some 15 times that now in the atmosphere, has presumably gone into oxygen sinks such as oxidation of iron, sulfur, and volcanic gases. Cloud examined the balance between the total carbon and the total oxygen in the atmosphere, hydrosphere, biosphere, and sedimentary lithosphere and found that they are approximately in the proportions which would combine to form carbon dioxide (*5*). Although the assumptions are many in such calculations, the approximate balance lends strength to the argument that photosynthesis could account for the oxygen in the atmosphere.

The rate at which organic carbon is being buried in sediments of the deep oceans indicates that only 4 of every 10,000 g of carbon produced by photosynthesis becomes part of sedimentary rocks (*6*). Although this fraction is small, the great length of time which the reduced carbon resides in sedimentary rocks before it is eroded and oxidized accounts for the huge carbon mass which has accumulated and helps stabilize the free oxygen reservoir.

The length of the residence time is determined by the average rate of recycling of shales by erosion which has been estimated by Garrels and Mackenzie to correspond to a "half-mass life" of 600 million years (*7*). This means that only half of the carbon stored in shales would be subjected to weathering and oxidation in 600 million years, and it would presumably be replaced by about the same amount of carbon buried with new shales formed during this period.

If the organic content of shales has been fairly constant through the past