early stages of salt-water adaptation. The development of a thicker mucosal layer per unit length of intestine may be a critical factor in salt and water transport.

Three weeks after F. heteroclitus was transferred to fresh-water, gill filament QO_2 had decreased 30% ($P < 0.05$). Otherwise, there was no relationship between QO_2 and ion transport in the gill.

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1969 #13

REFLEX CONTROL OF GILL RESISTANCE AND HEART RATE IN S. acanthias

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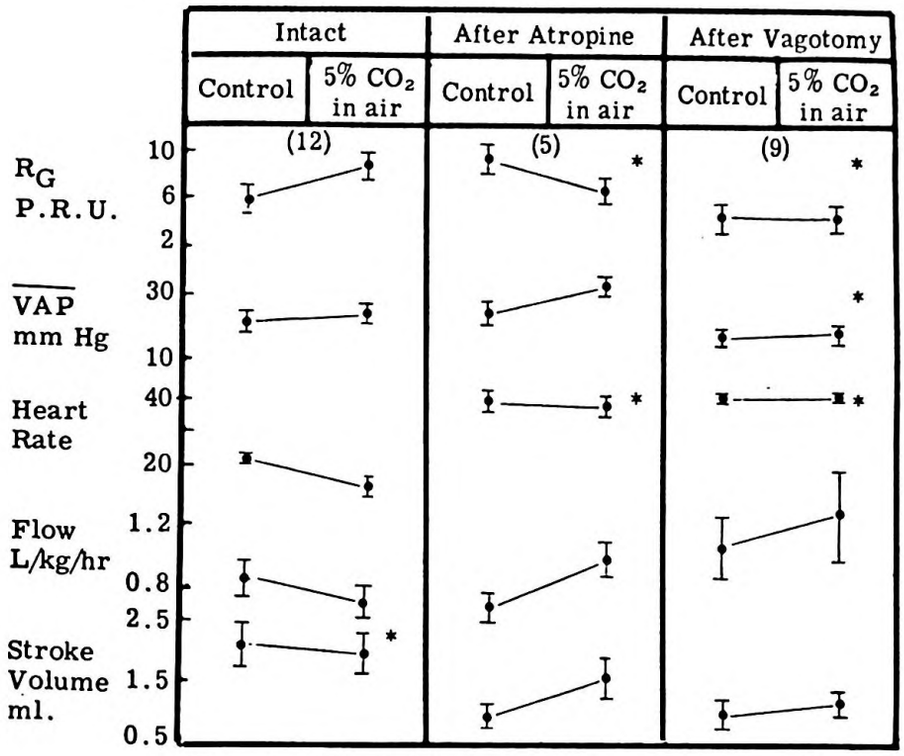
A vagally mediated cardio-inhibitory response to a wide variety of stimuli has been of interest for many years (Biol. Bull. Woods Hole 59:170, 1930). Hypoxia and hypercapnia are known to be effective in producing this response in the dogfish (J. Exptl. Biol. 38:531, 1961). More recently it has been postulated that changes in O_2 or CO_2 in the sea water delivered to the gills induce vascular changes in the gill itself as well as bradycardia (J. Exptl. Biol. 39:503, 1962). In previous studies the interpretation of pressure and heart rate changes have been limited by the lack of cardiac output data. In this investigation, flow was measured, and the hemodynamics of a reflex response to elevated pCO_2 were described.

Twenty-five dogfish weighing between 1.5 and 6 kg were used; the preparation was the same as that described in Bull. MDIBL 8:20, 1968. Ventral aortic pressure (VAP) and dorsal aortic pressure (DAP) were recorded from appropriately placed cannulas and stroke volume was recorded from a 20 or 25 mm electromagnetic flow probe placed around the conus arteriosus. Flow ($\dot{Q}_B$) was calculated by integrating the stroke volume curve and was expressed in L/kg/hr. Gill resistance (R_G) was calculated from $(\overline{VAP} - \overline{DAP})/\dot{Q}_B$ and expressed in peripheral resistance units (PRU). In three fish an index of cardiac contractility was measured as described in Bull. MDIBL 8:20, 1968.

Seventeen of the fish were vagotomized, via an oro-pharyngeal approach, by section of the vagi at the medullary junction; nine of these were excluded from the study either because on autopsy the vagotomy was found to be incomplete, or because of rapid deterioration of the preparation after vagotomy. In eight fish the vagi were blocked pharmacologically with a 2.0 mg/kg dose of atropine. The fish were exposed to 10 minute periods of hypercapnia before and after either vagotomy or atropine by perfusing their gills with sea water equilibrated in a bubble equilibrator with 5% CO_2 in air as described in Bull. MDIBL 8:28, 1968. It is assumed that the elevated pCO_2 caused some desaturation of the blood due to a large Bohr effect and hypercapnia was most probably accompanied by some hypoxia.

Hemodynamic changes occurring when the intact dogfish was exposed to sea water equilibrated with 5% CO_2 in air, are shown in Figure 1, 1st panel. $\overline{VAP}$ rose although total cardiac output fell with a drop in heart rate and no change in stroke volume. The pressure drop across the gills widened as a result of both an increase in $\overline{VAP}$ and a decrease in $\overline{DAP}$. The calculated



* No significant difference between control and 5% CO_2 in air (Paired Student t test).

( ) No. of dogfish.

Figure 1. Points indicate mean values and the bar represents standard error of the mean. In all three groups control values were taken immediately before 5% CO_2 in air was added to sea water perfusing gills. The values taken during the period of 5% CO_2 in air administration are peak responses.

gill resistance, then, rose, since directional changes in both pressure and flow tended to increase it. When 3% CO_2 in O_2 was used as the equilibrating gas, similar changes were seen.

When atropine was given the most striking change occurred in heart rate which almost doubled in most fish. With the tachycardia stroke volume diminished, and the net effect in cardiac output was reduction. Although the difference in pressure between the ventral aorta and the dorsal aorta decreased after atropine, the proportionally greater decrease in flow resulted in an increase in the calculated gill resistance. A total vagotomy produced a preparation similar to the dogfish after atropine in that a marked tachycardia was accompanied by a diminution in stroke vaolume. External perfusion of the gills with 5% CO_2 in air in sea water produced qualitatively the same hemodynamic response in both the preparation after atropine and after vagotomy (Figure 1, 2nd and 3rd panel) but a different one from that in the intact fish. The change in heart rate was completely abolished and the gill resistance did not increase. Stroke volume, however, markedly increased bringing about a parallel increase in flow. With high flow rates, VAP and the pressure drop across the gills increased, but there was no significant change in calculated gill resistance.

When the intact dogfish is exposed to sea water equilibrated with 5% CO_2 in air, a dramatic rise in gill resistance is evident. This resistance rise is almost surely indicative of

vasoconstriction somewhere in the gill vasculature; this is the only plausible explanation for the set of circumstances where $\overline{VAP}$ rises with a fall in flow and dorsal aortic pressure. Since in mammals anoxia causes local vasoconstriction in the lungs, it is an attractive hypothesis that the active increase in gill resistance results from an intrinsic, local vasomotion. If this were the mechanism, however, gill resistance would be expected to show an even greater increase when cardiac output increase is an added feature of the response as in the preparations exposed to CO_2 after vagotomy and atropine. This is not the case; both pharmacological and surgical vagotomy abolish the rise in gill resistance altogether. It must be concluded that hypercapnia and anoxia have no direct local effect on gill vasculature, but that the change in blood gas does evoke a vagally mediated vasoconstriction. In report #28 this issue, external chemoreceptors are shown not to be a necessary sensory input, and pre-gill chemoreceptors are excluded as possible afferent inputs. Chemoreceptors in the efferent gill vasculature are a possibility and certainly hypercapnia and hypoxia may affect medullary centers in such a way as to increase motor vagal firing to the gills.

Central chemoreceptors have, in fact, been demonstrated in dogfish with the cardiac vagus intact and with section of the glossopharyngeal and the part of the vagus related to gill structures (J. Exptl. Biol. 38:531, 1961). In such a preparation anoxia caused bradycardia, but when the cardiac vagus was cut, no bradycardia was seen. Undoubtedly, cerebral anoxia plays a role in the heart rate response. Heart rate is also controlled by a baroreceptor reflex which slows the heart via the vagus in response to pressure increases in the ventral aorta (Biol. Bull. Woods Hole, 62:10, 1932). Such a reflex would become operative in our preparation secondary to the rise in gill resistance. Neither hypoxia nor hypercapnia produced bradycardia after removal of the nervous control of the heart. It is possible that a local stimulatory effect on heart rate could be masked by the inability of the heart to beat faster. An inotropic stimulation may be reflected in the increase in stroke volume. From measurements of max dp/dt, however, we were not able to demonstrate inotropic changes in three fish after atropine and 5% CO_2 in air. The stroke volume changes might also result from more complete filling if venous return were increased.

The idea of a vagally mediated vasoconstriction and bradycardia in the presence of hypercapnia and anoxia is not without precedent. The changes demonstrated in the dogfish are similar to those evoked by the diving reflex in seals and other mammals. Studies of further similarities would be interesting.

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1969 #14

TRANSPORT OF SUGARS INTO FLOUNDER TUBULES

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In a study program concerning the mechanism of sugar transport by renal tubular cells (cf. A. Kleinzeller; J. Kolínská; I. Beneš; Biochemical J. 104:843-60, 1967) the transport processes at the peritubular face of these cells were deemed to be of considerable interest. Therefore, the mechanism of transport of some sugars into teased tubules of flounder, Pseudopleuronectes americanus, kidney was studied. 0.5 - 1.0 mM D-galactose ^{14}C was transported into this prepa-