6. Cardiac massage caused resumption of a beat after prolonged potassium standstill and gave definite support to the blood pressure (Figure 4).

7. No flow could be detected by a small electromagnetic probe on the larger cephalic artery. To measure cardiac output some whasout method would probably be best, the material being injected directly into the ventricle and its dilution being measured.

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1967 #29

HEMODYNAMIC STUDIES IN *Squalus acanthias*

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Dogfish were restrained on their backs and supplied with fresh sea water pumped into their mouths or spiracles. The heart was exposed through a longitudinal midline incision dividing the pectoral girdle caudally (Figure 1). A square wave electromagnetic probe, 20 or 25 mm in circumference, was placed on the aortic conus to measure cardiac output ($\dot{Q}_B$). (Flow meter: Carolina Electronics). The flow pulse was integrated on line with an operational amplifier circuit to

Figure 1

obtain the stroke volume (SV) (submitted, Medical Research Engineering). Pressures were obtained by appropriately placed needles or catheters. Ventricular washout curves were obtained by means of a needle thermistor passed through the ventricular wall and out the aortic conus to the ventral aorta. For this purpose, resistance changes were recorded following a ventricular injection of 0.25 to 0.5 ml of room temperature saline via a small polyethylene spray catheter. Ejection fractions (EF) were calculated from the thermal washout steps (Figure 2).

Electrical pacing, using a 1.5 volt ventricular stimulus, was carried out at rates from 2 to 60/min in preparations that exhibited bradycardia or standstill. Persistent ventricular fibrillation was treated with 0.1 ml saturated KCl injected directly into the ventricle. Epinephrine, 1 μg

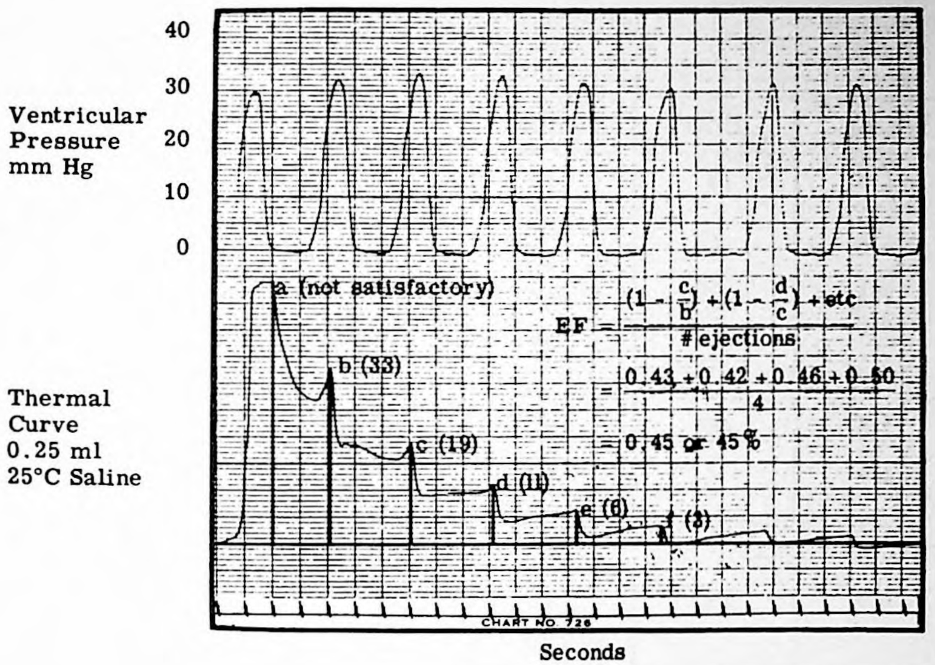


Figure 2

to 1 mg, was injected intra-arterially. The maximum pressure response and the time for it to return 50% toward its baseline were determined.

Preparations showed relatively stable acid-base parameters and $\dot{Q}_B$ for 3 to 4 hours. Some fish bled and gradually deteriorated hemodynamically. The aortic conus participated in the contraction of the ventricle producing bizarre flow waves unless the probe fitted snugly. Constant attention to the base line (0 flow) was required. Table 1 gives normal data for 19 fish. Values of $\dot{Q}_B$ are slightly lower than those of Murdaugh et al. (Amer. J. Physiol. 209:723-26, 1965), measured by a dye dilution method (1.60 ± 1.00 L/kg/hr). Figure 3 shows the relationship of $\dot{Q}_B$ and body weight (b). Line (a) shows data of Murdaugh et al.

Table 2 shows data from the thermal washout combined with as nearly concurrent stroke volumes as possible. The values for EF are much lower than expected since the beating fish heart appears to empty almost completely and postmortem will not readily accept volumes as

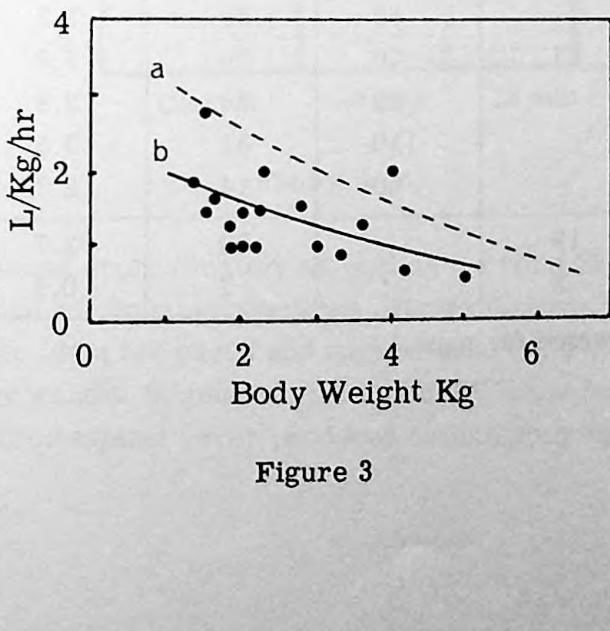


Figure 3

Table 1

#	Wt. Kg.*	Hcrt	Time	Rate	SV†	$\dot{Q}_B$†	Av. $\dot{Q}_B$
1	1.3	13	15	30	1.4	1.9	1.8
			45	21	2.2	2.1	
			75	20	1.3	1.3	
2	1.4	20	30	13	2.2	1.2	1.5
			45	15	2.4	1.6	
			75	18	2.1	1.6	
3	1.5	19	45	20	3.5	2.8	2.8
4	1.6	-	45	13	3.2	1.5	1.6
			70	15	2.8	1.5	
			160	17	3.0	1.9	
5	1.8	19	25	18	1.4	0.9	1.0
			120	23	1.4	1.1	
6	1.9	21	170	23	2.2	1.3	1.3
7	1.9	19	85	12	2.5	1.0	1.0
8	2.0	-	125	17	2.1	1.1	1.5
			135	19	2.9	1.7	
			165	18	2.8	1.5	
			210	21	2.8	1.7	
9	2.0	19	40	17	3.4	1.7	1.7
10	2.2	20	115	18	2.0	1.0	1.0
11	2.9	17	90	26	2.5	1.3	1.3
12	3.0	21	80	15	3.5	1.0	1.0
13	3.2	20	100	15	3.6	1.0	1.0
14	3.3	22	85	19	2.2	0.9	0.9
15	3.5	19	160	19	2.2	0.7	0.7
16	3.6	23	55	20	3.8	1.3	1.3
17	4.0	19	25	36	2.6	1.6	1.5
			55	22	4.0	1.3	
			65	38	2.3	1.5	
18	4.0	17	70	30	5.2	2.4	2.0
			80	30	3.8	1.8	
			110	33	3.5	1.7	
19	5.0	-	60	14	2.7	0.6	0.6
Mean	3.8	19		20	2.7	1.43	1.34
S.D.	1.1	2		7	0.9	0.49	0.50

*Female weights corrected for pups.

†As in Table 2.

Table 2

#	Wt. Kg.	Rate	$\dot{Q}_B$	SV	EF	EDV	ESV
9	2.0	17	1.7	3.4	45	7.6	4.2
10	2.2	18	1.0	2.0	47	4.3	2.3
13	3.2	20	1.2	3.2	51	6.3	3.1
16	3.6	20	1.3	3.8	48	7.9	4.1
17	4.0	32	1.5	3.0	55	5.5	2.5
18	4.0	31	1.9	4.1	38	10.8	6.7
Mean	3.2	23	1.4	3.3	47	7.1	3.8
S.D.	0.8	6	0.3	0.7	5	2.1	1.5

SV = Stroke volume (ml)
$\dot{Q}_B$ = Cardiac output L/kg/hr
EF = Ejection fraction (%)
EDV = End diastolic volume (ml)
ESV = End systolic volume (ml)

large as the calculated end diastolic volumes. In Squalus acanthias, the ventricular volume is small and blood is in intimate contact with the heart wall. It would be reasonable to expect the ventricular wall to change temperature rapidly after the thermal injection. This would lead to a slow washout and erroneously low EF. Studies should be repeated using washout of some substance that cannot diffuse into the ventricular wall. An ascorbic acid injection with a platinum black electrode sensing element might be satisfactory.

Epinephrine produced large maximum changes in pressure and these persisted for many minutes (Figure 4). Results are comparable to those found in the hypothermic dog and can best be explained by slow enzymatic destruction of the epinephrine. KCl was a satisfactory drug to effect reversion of ventricular fibrillation (Figure 5).

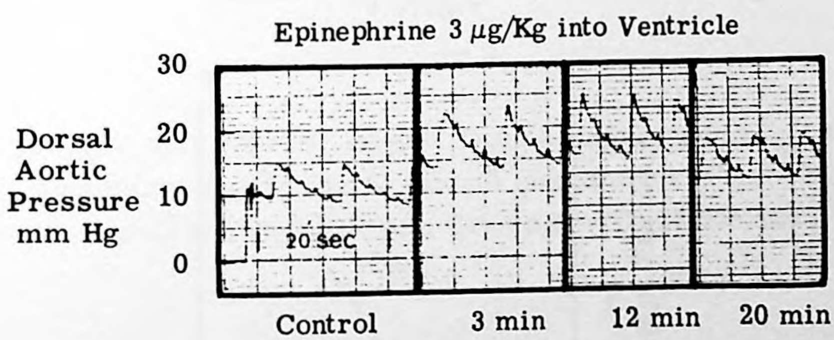


Figure 4

The paced heart functioned approximately as well as the normally excited heart, provided the rate was within that usual for Squalus acanthias. Figure 6 shows the variation in SV per kg that occurs with rate change (data for paced and unpaced hearts). Figure 7 shows the relationship of heart weight to body weight. In general, maximum SV exceeded heart weight, especially in the smaller fish. Slow rates almost never produced satisfactory values for $\dot{Q}_B$ (Figure 8).

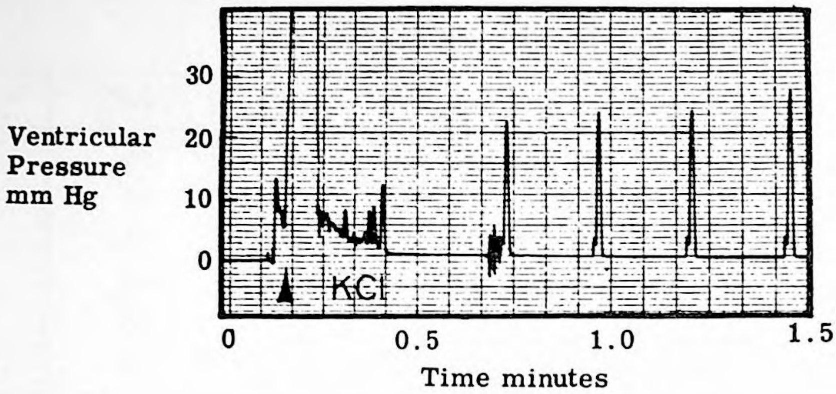


Figure 5

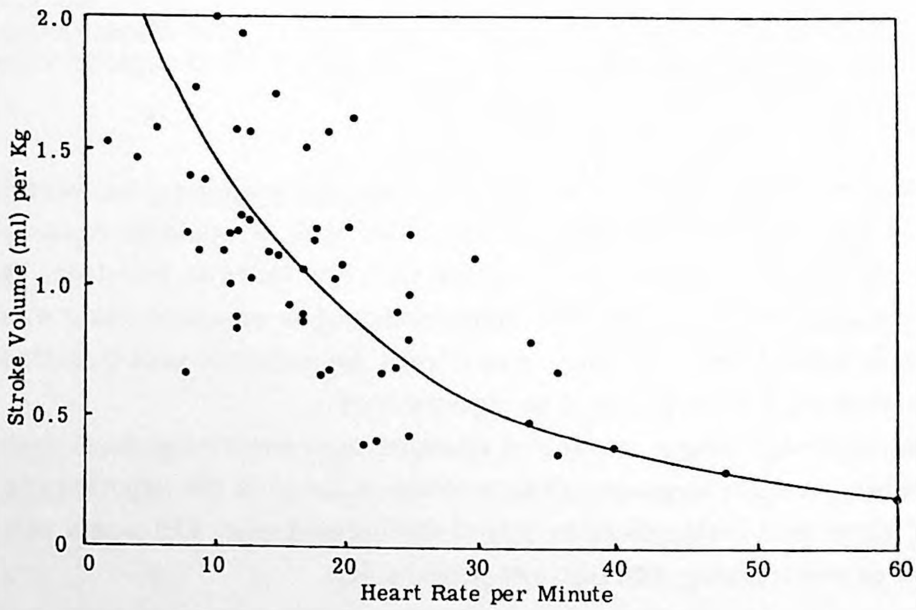


Figure 6

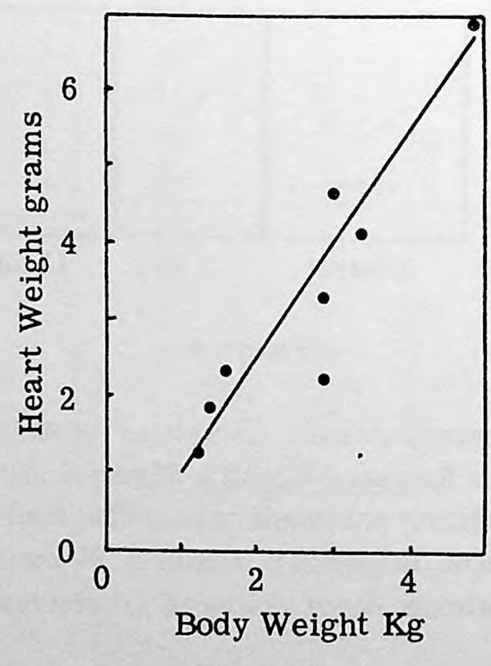


Figure 7

Fish with bradycardia (4.3/min) paced electrically 12-36/min.

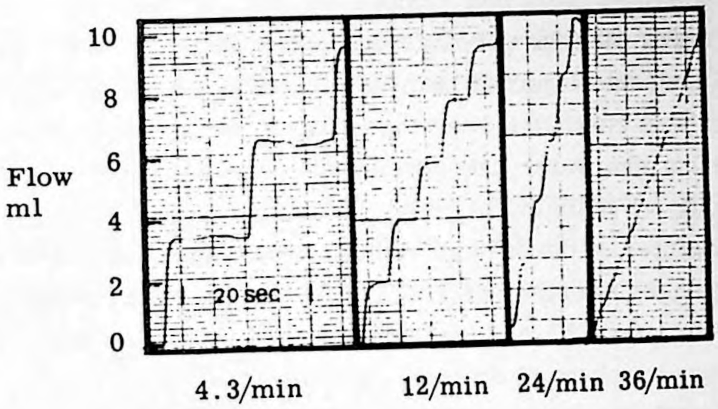
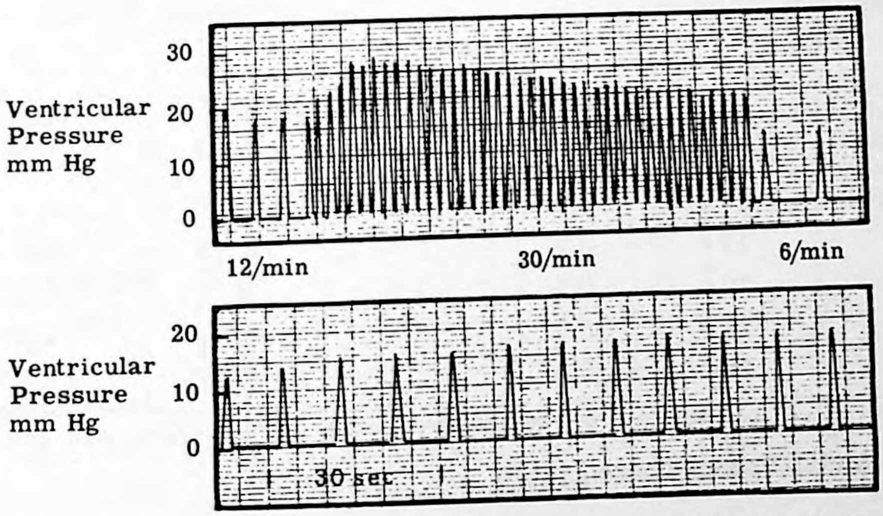


Figure 8



The pressure stabilizes at the same level when rate is changed by pacing.

Figure 9

Most hearts would not pace above 40 per minute. Over a wide range of $\dot{Q}_B$, aortic pressure was relatively constant, suggesting strong neural control mechanisms (Figure 9).

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1967 #30

EFFECTS OF TRICAINE METHANESULPHONATE (MS 222) ON THE CIRCULATION OF Squalus acanthias

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MS 222 (tricaine methanesulphonate, Sandoz) is recommended for the immobilization of cold blooded animals, but has been found to reduce cardiac output ($\dot{Q}_B$) in Squalus acanthias, as shown by changes in cardiac green dye curves (Murdaugh, V. and Robin, E. D., oral communication