is that the eel pout does this with a comparatively smaller heart. Thus on a per gram dry weight of myocardium basis, the power output of the eel pout is 66% greater than that of the sea raven. In light of the power output generated by the eel pout heart, the significantly lower P_{VO_2} (about 40% lower) is surprising.

That the myoglobin-less eel pout heart can function at least as well as a myoglobin-rich heart and with a presumably lower O_2 gradient is the opposite of the expected finding.

DISCUSSION

It should be stressed that results are preliminary findings and compare only two teleost species. The P_{VA} and $\dot{Q}_{VA}$ for both fish are within the ranges for other marine teleosts. Consequently, the difference in power output is not too outstanding if the range of power output values found in other teleosts is considered. For instance, the power output in the red heart of the lingcod (Ophiodon elongatus) at 10°C is 0.9×10^4 ergs. s^{-1}.kg body wt^{-1}, which probably lies between the eel pout and sea raven values for 17°C, given an allowance for the 7°C temperature difference.

The resting P_{VO_2} of the sea raven is similar to the P_{VO_2} found in other teleosts. Thus the P_{VO_2} of eel pout is low amongst teleost fish. Whether ventral aortic P_{O_2} indicates the true ventricular lumen blood $P_{\bar{O}_2}$ may be challenged. We feel that the measured P_{VO_2} is however a representative value since Kiceniuk and Jones (J. Exp. Biol. 69:247-260, 1977) could not detect a significant P_{O_2} difference between blood entering and leaving the heart in the trout (Salmo gairdneri).

The present findings illustrate that a myoglobin-less fish heart can perform equally as well as a myoglobin-rich one, but with a less favorable O_2 gradient. These findings are contradictory to those expected and therefore raise profound questions as to the role of myoglobin in fish hearts. This work was supported by a grant to W.R.D. from the New Brunswick Heart Foundation, Canada. The use of Dr. B. Kent's P_{O_2} meter was appreciated and M. Levy is thanked for his assistance with the P_{O_2} measurements.

RATES OF OXYGEN CONSUMPTION AND LACTATE OXIDATION BY PERFUSED ISOLATED OCEAN POUT AND SEA RAVEN HEARTS

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In contrast to most vertebrate species the heart of the ocean pout (Macrozoarces americanus) is almost devoid of myoglobin. It would be of interest to ascertain if the absence of myoglobin which is thought to facilitate intracellular oxygen diffusion is associated with alterations in the organization of aerobic energy metabolism. This problem is being approached by determining the rates of oxygen consumption and $^{14}CO_2$ production from labelled substrate by perfused isolated hearts. For comparative purposes studies are being conducted with myoglobin poor white hearts from ocean pout and myoglobin-rich red hearts from sea raven (Hemitripterus americanus). These species present ideal experimental models since both animals are lethargic bottom dwellers, suggesting similar levels of blood gases and moreover both species have very poorly developed coronary arteries, thus their myocardia must receive oxygen and nutrients from the blood which is in the ventricular lumen.

MATERIALS AND METHODS

Ocean pout (Macrozoarces americanus) and sea raven (Hemitripterus americanus) were captured by otter trawl in either Passamaquoddy Bay, N.B. or Seal Cove, Maine. The fish were transported to the laboratory and maintained at 10° - 13°C. Animals were sacrificed by severing the spinal cord, the hearts were exposed, excised and placed in

cold perfusion media. The basic perfusion media was gassed with either air: 1% CO_2 or 99% O_2: 1% CO_2; had a final pH of 7.8 and contained the following in mM : NaCl 149, $CaCl_2$ 3.0, KCl 4.5, $MgSO_4$ 2.0, KH_2PO_4 0.5, Na_2HPO_4 2.0, $NaHCO_3$ 32. The perfusate was maintained at 10°C and all hearts were electrically paced at 30 beats per min.

In the oxygen consumption studies perfusate gassed with air: 1% CO_2 and containing 5 mM glucose was delivered into the sinus venosus at a filling pressure of 1.5 cm H_2O via a cannula constructed from PE 260 tubing. The heart filled and emptied its contents by ventricular contraction through the cannulated ventral aorta against a pressure head of either 5 or 15 cm H_2O. The input side of the preparation incorporated a one way valve to prevent backflow during systole. The output side of the preparation incorporated an in-line flow meter transducer and a pressure transducer at the level of the heart. All signals were displayed on a Narco MK-III physiograph (see Driedzic, Physiol. Zool. 51:42-50, 1978 for details). Heart power output was calculated from the product of flow times net average pressure development. Oxygen consumption was determined from the difference in oxygen tension before and after passage through the heart times the flow rate. Oxygen tension was determined with a Radiometer blood gas analyser with associated water jacketed O_2 electrode.

In the $^{14}CO_2$ production studies, hearts were force filled at a constant flow rate of 15 ml/min via an atrial cannula with the perfusate being expelled through the severed ventral aorta. The perfusion apparatus consisted of a recirculating system in which CO_2 was collected in sealed traps (Lanctin, McMorran and Driedzic, Can J. Zool. 58:1708-1711, 1980). Hearts were perfused for 30 min with buffer gassed with 99% O_2 : 1% CO_2 containing ^{14}C-lactate. The total volume of recirculating perfusate was 25 ml. The initial specific activity of lactate was adjusted to insure greater than 10,000 cpm in the CO_2 traps.

RESULTS AND DISCUSSION

The mechanical performance and oxygen consumption data are presented in Table 1. Although there are

Table 1.--Rates of Power Output and Oxygen Consumption by Perfused Isolated Ocean Pout and Sea Raven Hearts. All Values Represent the Mean ± S.E. on the Basis of 4-6 Individuals

	Afterload (cm H_2O)	Power output (erg·g dry wt^{-1}·sec^{-1})(10^3)	Oxygen consumption (μl·gm dry wt^{-1}·sec^{-1})	Percentage efficiency
Ocean pout	5	6.32 ± 1.99	2.09 ± 0.38	1.47
	15	11.17 ± 2.66	1.63 ± 0.19	3.35
Sea raven	5	9.79 ± 1.85	1.26 ± 0.16	3.88
	15	17.82 ± 2.82	2.04 ± 0.52	4.27

differences in power development between the two species under similar perfusion conditions the oxygen consumption data may be considered to be qualitatively similar. Thus despite a ten-fold difference in myoglobin content between the two heart types (Driedzic et al., this Bulletin) the rates of oxygen consumption encompass overlapping ranges. It should be noted that the in vitro power output recorded here is only about 1/10 of the in vivo resting level of cardiac power development (Farrell and Driedzic, this Bulletin). The oxygen consumption values may therefore not reflect maximum rates attainable.

The rates of oxidation of exogenous lactate are presented in Table 2. At 2 mM lactate the rate of $^{14}CO_2$

Table 2.--Rates of Lactate Oxidation by Perfused Isolated Ocean Pout and Sea Raven Hearts. Data are Expressed as μmoles of Substrate Oxidized·gm dry weight^{-1}·hr^{-1}. All Values Represent The Mean ± S.E. On the Basis of 4-6 Individuals

Lactate concentration	3 - ^{14}C-Lactate	U - ^{14}C-Lactate
	OCEAN POUT	
2 mM	27.6 ± 3.5	26.7 ± 5.2
10 mM	46.8 ± 4.1	150.9 ± 9.7
	SEA RAVEN	
2 mM	2.1 ± 0.4	9.6 ± 2.8
10 mM	8.1 ± 2.0	19.4 ± 3.1
15 mM	5.9 ± 2.1	33.4 ± 5.1

production from 3-^{14}C-lactate is equivalent to that from U-^{14}C-lactate for the ocean pout hearts. In the sea raven hearts though rates of $^{14}CO_2$ production from the latter substrate are 4-5 fold higher than from 3-^{14}C-lactate. As the availability of exogenous lactate increases the ratio of $^{14}CO_2$ production from 3-^{14}C-lactate to $^{14}CO_2$ production from U-^{14}C-lactate decreases for both heart types. The oxidation of 3-^{14}C-lactate leads to the production of $^{14}CO_2$ only by reactions catalyzed by enzymes of the citric acid cycle; whereas, in addition to these sites U-^{14}C-lactate liberates $^{14}CO_2$ in concert with the production of acetyl CoA at the pyruvate dehydrogenase reaction. Thus, at 2 mM lactate essentially all the oxidized substrate is channelled through the citric acid cycle in the ocean pout hearts but only about 1/4 of the oxidized substrate enters the cycle in the sea raven hearts. That is, in the myoglobinrich hearts a higher proportion of the lactate undergoes the first decarboxylation only and is subsequently directed elsewhere probably into lipid synthesis. At all higher concentrations of exogenous lactate the proportion of lactate directed into the citric acid cycle decreases for both ocean pout and sea raven hearts.

In conclusion, at low work rates the ocean pout and sea raven hearts display similar rates of oxygen consumption even though their intracellular content of myoglobin is very different. It is possible that the role of myoglobin in terms of facilitating intracellular oxygen diffusion becomes important only at high rates of metabolism. Under conditions of low mechanical work the ocean pout heart appears particularly well designed to utilize exogenous lactate as a metabolic fuel whereas lactate oxidation in the sea raven heart is less vigorous. The relationship between the presence or absence of myoglobin and lactate metabolism is presently under investigation. This work was supported in part by a grant from the N.B. Heart Foundation. We would like to thank Dr. Barbara Kent for the generous use of the oxygen meter.

MYOGLOBIN CONTENT AND MAXIMAL ACTIVITIES OF ENZYMES OF ENERGY METABOLISM IN FISH WHITE HEART AND SKELETAL MUSCLE

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It is well recognized that there are significant differences amongst muscle types with respect to patterns of metabolic fuel utilization. White skeletal muscle for instance, is characterized by low myoglobin and mitochondrial content but high levels of glycolytic enzymes. White muscle generates a high proportion of the ATP required to