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Cardiac Dynamics of Intact, Splenectomized and Hepatic Artery Ligated Dogs During Acute Oligemic Shock.* (28841)

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Shock has been said to be a problem of combined failure of the circulatory system (1). Myocardial deterioration, as a result of reduction in coronary flow(2-6) and thus a decrease in oxygen availability, is a major contributor to circulatory failure in irreversible hemorrhagic shock(7,8). In oligemic shock cardiac output is markedly reduced (2-5) as a result of a decrease in venous return. This situation and other conditions requiring increased cardiac output are attended by splenic contraction(9). In the intact dog, hemorrhage invariably produces a reduction in size of the spleen(9,10), while the response of the liver is extremely variable(9). Thus the splenectomized dog is more vulnerable than the intact animal to the consequences of oligemic shock when equal volumes of blood (on the basis of body weight), are removed from each animal(11,12). When both are bled to the same hypotensive level, however, this hemodynamic disadvantage should be nullified, for the contribution of the spleen in the intact animal would only necessitate removal of a greater blood volume in order to achieve the desired blood pressure level. Under this condition a finding of a greater depression in cardiac performance in the splenectomized animal could not be completely explained by the lack of reservoir function, and may imply a humoral contribution by the spleen in the intact animal. In the present study myocardial responses were observed in intact, splenectomized, and hepatic artery ligated dogs bled to a mean arterial blood pressure of 40 mm Hg.

Methods. A total of 41 mongrel dogs, comprising 3 groups, were used in 41 experiments. Group I consisted of 11 intact (control) animals, 15.1 to 26.6 kg in weight; Group II, 14 animals, 14.0 to 24.2 kg, which had undergone removal of their arterial supply to the liver(13) more than 300 days prior to the experiment; Group III, 16 animals, 10.5 to 21.4 kg, splenectomized 3-13 months prior to the study. Each animal was anesthetized with sodium pentobarbital (30 mg/kg) and heparinized (5 mg/kg). The procedure for positioning of the catheters at various sites, and the methods employed for determination of oxygen consumption, blood oxygen content, cardiac output (Fick), coronary blood flow (nitrous oxide), and other parameters were the same as previously outlined(4). Calculations of various metabolic and hemodynamic functions of the myocardium were made using the equations of Bing *et al*(14).

Following control observations, the animals were bled freely from a femoral artery cannula until the mean arterial blood pressure reached 40 mm Hg. The time required to reach this level and the volume of blood removed were recorded. Arterial pressure was maintained at 40 mm Hg for one hour by withdrawing or infusing blood. At the end of this time the additional volume of blood removed or infused was recorded. Cardiovascular and metabolic determinations were made when the pressure first reached 40 mm Hg and one hour later.

Most of the animals employed were sacrificed after the experiment, thus no attempt

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TABLE I. Initial Volume of Blood Loss and Time Necessary to Decrease Mean Arterial Blood Pressure of Freely Bled Dogs to 40 mm Hg, and Additional Volume of Blood Withdrawn Necessary to Maintain This Pressure Level for One Hour. Means are given ± standard error.

	Group I	Group II	Group III
Body wt, kg	19.5 ± .98	18.6 ± .70	15.6 ± .96 *
Initial blood loss, ml	645 ±41.5	486 ±60.0	319 ±30.0 †
, % B.W.	3.32 ± .162	2.54 ± .231*	2.06 ± .158†
Time, min	11.5 ± .72	11.9 ± 2.48	5.62 ± .67 †
Additional vol, ml	208 ±30.7	158 ±31.3	122 ±15.8 *
Total blood loss, % B.W.	4.35 ± .273	3.41 ± .305*	2.87 ± .188†

* Significant difference from control (Group I) at 5% level.
† *Idem* at 1% level.

is made to assess the survival rate of each group. Hemodynamic and metabolic observations made during oligemia are expressed as mean differences from their respective control values. Standard errors of the means are provided.

Results and discussion. The mean hemorrhagic time and mean initial blood loss necessary to achieve a mean pressure of 40 mm Hg in each group, as well as the additional volume of blood removed in order to maintain the pressure at this level, are given in Table I. The finding that the initial blood loss, bleeding time, and total blood loss were significantly lower in the splenectomized group, when compared to corresponding values of the intact animals, clearly demonstrates the reserve capacity of the spleen in the intact animal. The difference in total blood loss between these two groups, 14.8 ml/kg (1.48%), would suggest that the spleen contributes nearly 15% of the total circulating blood volume in the intact animal in this study. This figure is reached using a total blood volume (I^{131}) of 100 ml/kg(15, 16) for the dog anesthetized with sodium pentobarbital. Though this figure is higher than the 8% reported by Guntheroth and Mullins(9), others have reported that the spleen may contribute 16-20% of the total blood volume in the dog subjected to anoxia or hemorrhage(17). This difference may be due to relative enlargement of the spleen known to be produced by pentobarbital(9, 12,17). The initial blood loss in the hepatic artery ligated animals was also less than the value recorded for intact dogs. This finding suggests that the hepatic arterial vasculature may function as a reservoir in hypotensive states.

The hematocrits of Groups I and II were decreased only slightly, while a marked reduction was noted in the splenectomized animals (Table II). This observation is in agreement with the results of Carr and Essex(12) and is not surprising in view of the high red cell content of the spleen(17).

The cardiovascular and metabolic responses of each group are presented in Table II. The alterations observed in the various hemodynamic and metabolic functions tested in the intact group consequent to the hypotensive state produced by hemorrhage are in agreement with those of others(2-5,18). In this study the patterns of response observed in the other 2 groups were qualitatively and quantitatively similar to those exhibited by the intact group. Observations made in this study suggest that in oligemic states the spleen serves only to contribute blood volume and red cells in its capacity as a precisely regulated reservoir(9), and does not modify cardiac performance through another mechanism. Hepatic artery ligation does not affect the circulatory response, except possibly to facilitate venous return. This contribution, however, does not appear to approach that of the spleen.

Summary. Forty-one mongrel dogs, 11 intact animals, 14 subjected to hepatic artery ligation, and 16 splenectomized, anesthetized with pentobarbital, were each bled to a mean arterial blood pressure of 40 mm Hg and maintained at this level for one hour. The splenectomized animals required significantly less time to reach this pressure level and significantly less blood loss when compared to the intact group. The blood loss in the hepatic artery ligated animals was less than that for the intact dogs, but greater than the

TABLE II. Variations in Cardiovascular Functions as a Consequence of Acute Rapid Hemorrhage to a Mean Arterial Blood Pressure of 40 mm Hg. Values during the hypotensive period are expressed as mean differences from their respective controls. Standard errors of means are given under the mean values.

Item	Group I — Normal			Group II — Hepatic artery ligated			Group III — Splenectomized		
	Control	Change from control after hemorrhage: Immed	1 hr	Control	Change from control after hemorrhage: Immed	1 hr	Control	Change from control after hemorrhage: Immed	1 hr
Mean pressure, mm Hg, arterial	133 ± 5.6	− 95 ± 6.1	− 93 ± 7.7	132 ± 8.6	− 95 ± 9.3	− 86 ± 12.4	142 ± 7.0	− 101 ± 12.9	− 96 ± 9.2
Pulmonary artery	9.9 ± 1.2	− 3.5 ± 1.2	− 1.4 ± 1.3	15.6 ± 1.8	− 7.3 ± 1.4	− 7.8 ± 1.9	9.0 ± 1.0	− 5.0 ± 1.5	− 4.1 ± 1.8
Coronary sinus	4.3 ± .1	− 2.3 ± 1.7	− .8 ± .6	4.2 ± 1.8	− 2.1 ± 1.0	− 1.9 ± 1.5	2.6 ± .4	− 1.4 ± .4	− .2 ± 1.3
Heart rate per min	142 ± 8.5	+ 2.8 ± 6.4	+ 63 ± 8.5	166 ± 6.4	+ 21 ± 7.4	0 ± 13.5	156 ± 8.2	− 21 ± 9.2	+ 39.3 ± 12.1
Cardiac output, l/min	1.77 ± .20	− 1.13 ± .22	− 1.06 ± .32	2.49 ± .23	− 1.58 ± .29	− 1.22 ± .23	1.91 ± .15	− .97 ± .17	− .73 ± .21
Systemic vascular resistance, dynes Sec cm^{-5}	6401 ±1880	−1437 ± 286	−835 ±128	5360 ±181	−1674 ± 394	− 254 ±1390	6764 ±577	−2740 ± 206	+913 ±767
Coronary blood flow, ml/100 g L.V./min	83 ± 9.8	− 47 ± 11.9	− 33 ± 11.0	84 ± 7.9	− 42 ± 10.5	− 25 ± 19.0	91 ± 7.5	− 51 ± 5.8	− 16 ± 7.0
ml/L.V./min	51 ± 8.2	− 31 ± 9.1	− 21 ± 7.8	46 ± 3.8	− 22 ± 4.8	− 11 ± 5.1	43 ± 3.7	− 23 ± 10.0	− 8.7 ± 3.2
Coronary vascular resistance, units	1.81 ± .02	− .81 ± .51	− 1.08 ± .33	1.55 ± .20	− .63 ± .32	− .57 ± .34	1.57 ± .16	− .68 ± .17	− .66 ± .33
Blood oxygen content, vol %, arterial	16.4 ± .76	+ 1.2 ± .42	+ .2 ± .62	17.9 ± .62	− 1.6 ± .42	− 3.5 ± .68	16.2 ± .50	− 2.2 ± .41	− 3.9 ± .62
Coronary sinus	3.53 ± .03	− 1.78 ± 1.08	− 2.08 ± .49	3.38 ± .31	− 2.04 ± 2.91	− 2.14 ± .37	4.15 ± .41	− 2.96 ± .37	− 3.19 ± .37
A-MVO_2 diff	4.63 ± .41	+ 5.08 ± 1.30	+ 9.73 ± .46	4.51 ± .39	+ 6.26 ± .72	+ 6.38 ± .65	4.04 ± .21	+ 6.14 ± .42	+ 6.22 ± .60
Myocardial O_2 uptake, ml/L.V./min	6.5 ± 1.14	− 3.4 ± .99	− 2.1 ± 1.02	6.8 ± .66	− 3.2 ± .63	− 1.8 ± 1.51	5.2 ± .5	− 2.8 ± .4	− 1.2 ± .5
Aerobic energy uptake of L.V., kg/min	12.9 ± 2.3	− 6.9 ± 2.0	− 4.1 ± 2.0	13.7 ± 1.3	− 6.4 ± 1.3	− 3.5 ± 1.6	10.3 ± 1.0	− 5.5 ± .9	− 2.5 ± .9
Work of left ventricle, kg/min	3.2 ± .45	− 1.7 ± .48	− 2.1 ± .27	4.5 ± .89	− 4.2 ± .90	− 4.2 ± 1.28	3.6 ± .30	− 3.1 ± .32	− 3.0 ± .40

TABLE II (continued).

Item	Group I Normal			Group II Hepatic artery ligated			Group III Splenectomized		
	Control	Change from control after hemorrhage Immed	1 hr	Control	Change from control after hemorrhage Immed	1 hr	Control	Change from control after hemorrhage Immed	1 hr
Mechanical efficiency, %	39 ± 6.2	− 24 ± 9.4	− 24 ± 7.7	31 ± 5.4	− 23 ± 8.4	− 24 ± 7.1	38 ± 7.0	− 29 ± 8.0	− 32 ± 9.2
Hematocrit, % arterial	45.2 ± 1.3	− 4.3 ± 2.2	− 4.3 ± 2.0	44.0 ± 1.4	− 1.3 ± .9	− 4.9 ± 1.3	43.3 ± 1.1	− 6.6 ± .8	− 11.4 ± 1.1
Pulmonary artery	44.1 ± 1.4	− .9 ± 1.5	− 3.3 ± 1.7	45.2 ± 1.9	− 3.3 ± 1.5	− 6.5 ± 1.5	42.5 ± 1.1	− 4.9 ± .3	− 8.5 ± .9
Coronary sinus	46.4 ± 1.4	− .8 ± 1.8	− 3.0 ± 1.6	45.1 ± 1.3	− 2.4 ± 1.4	− 3.0 ± 2.4	43.7 ± 1.5	− 6.4 ± .5	− 10.0 ± .9

blood loss recorded for the splenectomized group. During the period of hypotension hematocrit values were markedly reduced in the splenectomized animals, but not in the other groups. The patterns of hemodynamic and metabolic (coronary flow, cardiac output, myocardial O_2 uptake, etc) alterations observed consequent to the oligemic state in each group were qualitatively and quantitatively similar. It was concluded that the spleen does not modify cardiac performance by a mechanism other than in its capacity as a blood reservoir, and that hepatic artery ligation has no effect on the cardiac response to oligemic shock.

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