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Myocardial Blood Flow and Oxygen Consumption during Moderate Cardiac Tamponade: Role of Reflex Vasoconstriction[1] (40390)

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Cardiac tamponade is a state of cardiac compression due to elevation of pericardial pressure by accumulation of fluid or gas in the pericardial space. Elevated pericardial pressure tends to reduce coronary blood flow by compressing the coronary blood vessels and by lowering aortic pressure (1). Cardiac tamponade depresses aortic pressure by reducing cardiac filling during diastole, resulting in reduced stroke volume and cardiac output (2).

Reflex excitation of the sympathetic vasoconstrictor nerves acts to support aortic pressure during acute cardiovascular stresses, such as hemorrhagic hypotension (3). The importance of this compensatory reflex activity during cardiac tamponade has not yet been evaluated. In light of the elevated extravascular compressive force operating on the coronary vasculature during cardiac tamponade, it might be expected that reflex maintenance of aortic pressure would be critical in order for coronary blood flow to satisfy myocardial oxygen requirements.

The following experiments were undertaken to evaluate the contribution of the sympathetic vasoconstrictor nerves to the maintenance of aortic pressure during moderate cardiac tamponade and to determine whether reflex vasoconstriction is important in preserving myocardial oxygen supply/demand balance during this cardiovascular stress.

Materials and methods. Fourteen mongrel dogs (17–24 kg) of both sexes were anesthetized with either pentobarbital (30 mg/kg iv) or chloralose (100 mg/kg iv). After a left thoracotomy, dogs were ventilated with room air by a Harvard respiratory pump. Arterial PO_2, PCO_2, and pH were maintained at physiological levels by adjusting the respiratory pump and by adding 100% oxygen to the inspired gas mixture. To obtain blood samples and blood pressure measurements, catheters were positioned in (a) the aorta via the left femoral artery, (b) the left ventricle via the left carotid artery, and (c) the coronary sinus via the left jugular vein. A catheter was introduced through the pericardium and secured with a purse string suture. This catheter was connected to a pump so that saline could be infused into the pericardial sac and to a transducer for measuring pericardial pressure. Limb lead II of the electrocardiogram was recorded and used to drive a cardiotachometer. After surgery, heparin (500 units/kg) was injected to prevent coagulation.

Cardiac tamponade was induced in fourteen animals with intact autonomic reflexes and again in eight of these animals after their reflexes were modified by systemic alpha adrenergic blockade. Alpha blockade was produced by intravenous infusion of phenoxybenzamine HCl, 1 mg/kg in 300 ml of isotonic saline over 45 min. Complete blockade was confirmed by a lack of pressor response following intravenous injection of 2 mg of the alpha agonist, methoxamine. Dogs treated with phenoxybenzamine received 300 ml of blood obtained from donor dogs to help maintain aortic pressure.

After control measurements were made, cardiac tamponade sufficient to reduce aortic pressure approximately 10% in dogs with intact reflexes was induced by elevating the pericardial pressure to about 6 mmHg. This was accomplished by infusion of 60–172 ml of 37° isotonic saline into the pericardial sac at approximately 13 ml/min. Measurements were made when hemodynamic parameters were stable for at least 3 min after initiation of cardiac tamponade.

Myocardial blood flow was measured with 9 ± 1 μ radioactive microspheres using the reference sample technique (4). Microspheres, labeled with either ^{46}Sc, ^{51}Cr, ^{85}Sr, or ^{141}Ce, were injected through a catheter

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advanced into the left atrium via a pulmonary vein. Beginning with injection of microspheres, reference arterial blood samples were collected for two consecutive 1-min periods through two catheters of different lengths inserted into the aorta via the left femoral artery. Comparison of the radioactivity in the duplicate reference blood samples provided a test for adequate mixing of microspheres in the systemic circulation. At the end of the experiment, the heart was excised and frozen for myocardial sampling. Subepicardial, midmyocardial and subendocardial tissue samples were obtained from four areas of the left ventricle. The myocardial tissue samples were weighed and their radioactivity determined by scintillation counting. The blood flow necessary to account for the radioactivity in an excised tissue sample was calculated from the equation:

$$MBF = RBF \times Mcpm \times 100/(Rcpm \times TW)$$

where:

MBF = calculated myocardial blood flow (ml/min/100g);
RBF = reference blood flow (ml/min);
Mcpm = myocardial counts per minute;
Rcpm = reference blood sample counts per minute;
TW = tissue weight (g).

Blood flow determinations of individual myocardial tissue samples were averaged to derive mean left ventricular blood flow.

Left ventricular oxygen consumption in the steady state was calculated from the Fick principle as the product of the mean left ventricular blood flow and the left ventricular arteriovenous oxygen content difference.

The left ventricular arteriovenous oxygen content difference was determined from analysis of paired aortic and coronary sinus blood samples using the equation:

$$AV_{O_2}\ diff. = (Sa_{O_2} - Sv_{O_2}) \times gHb \times 1.36$$

where:

AV_{O_2} diff. = arteriovenous oxygen content difference (ml O_2/100 ml blood);
$Sa_{O_2}-Sv_{O_2}$ = arteriovenous oxygen saturation difference (%);
gHb = hemoglobin concentration (g/100 ml blood);
1.36 = carrying capacity of hemoglobin for oxygen (ml O_2/g).

Blood PO_2, PCO_2, and pH were measured electrometrically (Instrumentation Laboratory, Model 113). PO_2 and pH values were used in conjunction with a nomogram derived specifically for dog blood (5) to determine the oxygen saturation of blood samples. Hemoglobin concentrations were measured spectrophotometrically.

To determine the role of reflex vasoconstriction on aortic pressure, myocardial blood flow and myocardial oxygen consumption during cardiac tamponade, responses to elevated pericardial pressure were compared before and after alpha blockade. Experimental group means were compared by the Student's *t*-test (6). A value of $P < .05$ was considered significant.

Results. The effect of cardiac tamponade on myocardial blood flow, myocardial oxygen consumption, and other hemodynamic parameters is presented in Table I. The choice of anesthetic did not alter the response to cardiac tamponade, and, therefore, data were pooled for analysis.

Moderate cardiac tamponade, induced by raising pericardial pressure to 6 mmHg, caused a 10% decrease in aortic pressure before alpha blockade and 36% decrease in aortic pressure after alpha blockade. Before alpha blockade, cardiac tamponade resulted in a 25% decrease in myocardial blood flow and in a 19% decrease in myocardial oxygen consumption. In spite of the more pronounced decline in aortic pressure caused by cardiac tamponade in dogs with alpha blockade, tamponade-induced changes in myocardial blood flow and myocardial oxygen consumption were independent of alpha blockade. In the unblocked animals, the fall in myocardial blood flow was associated with both a decline in aortic pressure and an increase in coronary vascular resistance. Alpha blockade eliminated the effect of cardiac tamponade on coronary vascular resistance. There was no disproportionate effect of cardiac tamponade on blood flow to any transmural region of the left ventricular wall either before or after alpha blockade.

It should be noted that alpha blockade itself caused significant decreases in aortic pressure and coronary vascular resistance but did not significantly change myocardial oxygen consumption or myocardial blood flow. For this reason, the results in Table I have

TABLE I. CHANGES IN MYOCARDIAL BLOOD FLOW, MYOCARDIAL OXYGEN CONSUMPTION, AND HEMODYNAMIC PARAMETERS DURING MODERATE CARDIAC TAMPONADE (TAMP) BEFORE AND AFTER α ADRENERGIC BLOCKADE (AB).[a]

	Experimental groups			
	Before AB ($n = 14$)		After AB ($n = 8$)	
	Control	TAMP	Control	TAMP
Pericardial pressure (mmHg)	0.5 ± 0.2	6.4 ± 0.7[c]	0.4 ± 0.3	5.9 ± 0.3[c]
Aortic pressure (mmHg)	117 ± 4	106 ± 6[c]	81 ± 8[b]	53 ± 7[c, d]
Myocardial blood flow (ml/min/100g)	110 ± 10	78 ± 8[c]	126 ± 15	86 ± 18[c]
Myocardial O_2 consumption (ml/min/100g)	10.0 ± 0.8	7.9 ± 0.6[c]	13.2 ± 1.8	11.0 ± 1.6[c]
Coronary O_2 extraction (%)	60 ± 1	59 ± 4	62 ± 5	74 ± 4[c, d]
Coronary sinus pH	7.37 ± 0.01	7.36 ± 0.02	7.18 ± 0.06[b]	7.15 ± 0.06[d]
Coronary vascular resistance (mmHg/ml/min/100g)	1.2 ± 0.1	1.5 ± 0.2[c]	0.7 ± 0.2[b]	0.6 ± 0.1[d]
Heart rate (beats/min)	163 ± 9	167 ± 10	209 ± 13[b]	214 ± 13[d]
Left ventricular end-diastolic pressure (mmHg)	4.2 ± 0.7	6.8 ± 0.8[c]	2.6 ± 0.9	4.6 ± 1.1[c]

[a] Values are mean ± SEM.
[b] $P < .05$, Control vs. Control.
[c] $P < .05$, TAMP vs. respective Control.
[d] $P < .05$, TAMP vs. TAMP.

been described above in terms of percent change from their respective control.

Discussion. This study demonstrated that the sympathetic vasoconstrictor reflex attenuates the fall in aortic pressure during cardiac tamponade as it does during other cardiovascular stresses. This mechanism is likely mediated via arterial baroreceptors. To test the possibility that the depressive action of pentobarbital on circulatory reflexes (7) had exaggerated the fall in aortic pressure during cardiac tamponade, studies were also conducted using chloralose, an anesthetic known to exaggerate circulatory reflexes (8). Under the conditions of these experiments, chloralose anesthesia did not result in a significantly different aortic pressure or myocardial blood flow during cardiac tamponade.

Consistent with findings of earlier investigators (9) we observed a fall in myocardial oxygen consumption during cardiac tamponade. This decrease appears due to a reduction in the work load of the heart rather than due to inadequate myocardial blood flow. Several observations support this conclusion. Firstly, the coronary vascular resistance increased during cardiac tamponade although the potential for coronary vascular dilation existed as was demonstrated during cardiac tamponade after α adrenergic blockade. Secondly, there appeared to be no imbalance between oxygen supply and demand since there was no increase in coronary oxygen extraction during cardiac tamponade. Thirdly, there seemed to be no increase in anaerobic metabolism by myocardium since there was no decrease in the pH of coronary sinus blood. This final point is consistent with the observation of Frank *et al.* (9) that cardiac tamponade had no effect on pyruvate-lactate substrate utilization by myocardium.

Considering the major determinants of myocardial oxygen consumption, myocardial contractility, heart rate, and left ventricular wall tension (10), one can speculate as to the reason for the fall in myocardial oxygen consumption during cardiac tamponade. In spite of the fact that no direct measure of myocar-

dial contractility was made in this study, other investigators have reported either no change (9) or an increase (1) in this parameter during moderate cardiac tamponade. With no significant change in heart rate, it is likely that the fall in myocardial oxygen consumption was due to a reduction in left ventricular wall tension. In accordance with the Law of Laplace, this decrease in wall tension could be attributed to reductions in left ventricular pressure and chamber radius.

It is apparent from the present study that an adequate supply of oxygen to myocardium during cardiac tamponade does not depend on reflex vasoconstriction. Myocardial blood flow was capable of meeting myocardial oxygen requirements during cardiac tamponade whether or not sympathetic vasoconstrictor nerves were functional at peripheral alpha receptors. Before alpha adrenergic blockade, the fall in myocardial blood flow during cardiac tamponade was due to a decrease in aortic pressure with a concomitant increase in coronary vascular resistance. Even so, coronary blood flow was adequate to satisfy the oxidative energy requirement of the heart. Thus, despite compression of coronary vessels by elevated pericardial pressure, local control mechanisms were capable of matching myocardial blood flow to myocardial oxygen requirements. When reflex vasoconstriction was prevented by alpha adrenergic blockade, cardiac tamponade caused a more pronounced decrease in aortic pressure; however, myocardial blood flow was still adequate to meet the myocardial oxygen requirement. This was possible because a rise in coronary vascular resistance was averted in the face of elevated pericardial pressure. Apparently under these conditions, local metabolic dilation of coronary arterioles was of sufficient magnitude to nullify the physical compression of larger coronary vessels by the elevated pericardial pressure.

In conclusion, myocardial oxygen supply/demand balance during moderate cardiac tamponade depends primarily on local metabolic control of the coronary circulation and not on reflex maintenance of aortic pressure.

Summary. The influence of reflex vasoconstriction on aortic pressure and myocardial oxygen supply and demand during moderate cardiac tamponade was examined in anesthetized, open-chest dogs by comparing responses before and after systemic alpha adrenergic blockade. After α blockade, aortic pressure fell more during cardiac tamponade but there was no change in the ability of myocardium to satisfy its oxygen demand. The data suggest that although peripheral vasoconstriction attenuates the fall in aortic pressure during cardiac tamponade, adequate oxygen supply to myocardium depends on local metabolic vasodilatory systems that couple metabolism to coronary vascular tone, and not on this reflex adjustment.

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