

Hemodynamic Alterations and Regional Myocardial Blood Flow During Supraceliac Aortic Occlusion in Dogs With a Critical Coronary Stenosis

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The hemodynamic consequences and myocardial blood flow alterations associated with cross-clamping of the thoracic aorta were studied during pentobarbital (control), halothane (1 MAC), and isoflurane (1 MAC) anesthesia in dogs with a critical stenosis of the left circumflex coronary artery. Aortic clamping at the level of the diaphragm resulted in significant and equivalent increases in mean aortic pressure and left atrial pressure during the control clamp, halothane clamp, and isoflurane clamp periods. Likewise, aortic clamping resulted in a significant and equivalent decrease in cardiac output during control-clamp, halothane clamp, and isoflurane clamp. Myocardial contractility as assessed by dP/dt was depressed during halothane and isoflurane anesthesia when compared with control, but no further change in

contractility was associated with aortic clamping. No significant alterations in regional or transmural myocardial blood flow were found with halothane or isoflurane anesthesia, or with aortic clamping during halothane or isoflurane anesthesia. It is concluded that there are significant hemodynamic consequences associated with aortic clamping, that neither halothane nor isoflurane anesthesia alters these consequences when compared with pentobarbital anesthesia alone, and that the deterioration in myocardial function observed during aortic clamping with halothane and isoflurane anesthesia cannot be attributed to any maldistribution of myocardial blood flow.

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SURGICAL REPAIR of aortic aneurysms or occlusive disease requires occlusion of the aorta above the site of repair. Clamping of the aorta in this manner increases left ventricular (LV) afterload and preload, thereby increasing wall tension and myocardial oxygen demands. Such elevations may also decrease coronary perfusion pressure in the subendocardium if the elevation in end-diastolic pressure in the LV outweighs the increase in mean aortic pressure. Because many patients undergoing peripheral vascular surgery also have significant coronary artery disease (CAD), it is not surprising that aortic clamping has been associated with episodes of myocardial ischemia, dysrhythmias, and decreased cardiac output (CO).¹⁻⁴ The surgical mortality for such a procedure can be as high as 3% to 9%, and more than half of these deaths can be attributed to perioperative cardiac events.⁵⁻⁷

Recent reports that link intraoperative myocardial ischemia to the development of postoperative myocardial infarction emphasize the importance of anesthetic management that minimizes myocardial ischemia during high-risk operative procedures such as those involving aortic clamping.^{8,9} Myocardial ischemia occurs when the balance between oxygen supply and demand is inappropriate, either due to increased demand (increased wall tension, tachycardia) or decreased supply (limited coronary vasodilatation, decrease in perfusion pressure, inappropriate distribution of regional or transmural blood flow). The optimal anesthetic would be one that limits hemodynamic changes (control increases in wall tension and/or tachycardia) without adversely affecting myocardial oxygen supply, either globally or regionally. One technique for controlling the hemodynamic changes due to aortic occlusion is the use of the volatile anesthetics halothane or isoflurane.^{10,11} Halothane is known to reduce oxygen demand, but has negative

inotropic effects that may further increase LV end-diastolic pressure.¹²⁻¹⁴ Isoflurane has known vasodilating effects and, thus, can preserve CO despite a negative inotropic effect similar to that noted with halothane.¹⁵ By reducing the increase in afterload associated with aortic clamping, isoflurane could decrease myocardial oxygen demand and tend to protect the myocardium from ischemic injury. However, isoflurane's vasodilating effects could also jeopardize myocardial oxygen supply distal to coronary stenoses should a steal phenomenon occur.¹⁶⁻¹⁹

In an attempt to find an anesthetic technique that protects the compromised heart from the deleterious effects of aortic clamping, the hemodynamic and metabolic effects of isoflurane and halothane anesthesia were investigated during aortic clamping in dogs with a critical stenosis of a coronary artery. To determine the effect of these interventions on the transmural distribution of myocardial blood flow, the tracer-labeled radioactive microsphere technique was used.

MATERIALS AND METHODS

The protocol was approved by the Institutional Animal Care and Use Committee, and complied with the "Principles of Laboratory Animal Care" and the "Guide for the Care and Use of Laboratory Animals" (NIH Publication No. 80.23, revised 1978). Twenty-two mongrel dogs of either sex weighing between 18 and 25 kg were anesthetized with pentobarbital (30 mg/kg, intravenously [IV]),

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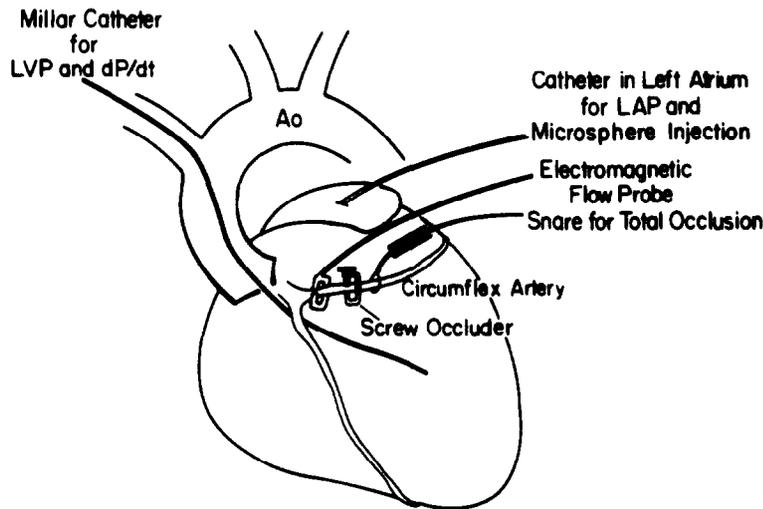


Fig 1. Cardiac schematic showing placement of monitoring catheters and instrumentation for creation of critical stenosis.

underwent endotracheal intubation, and were ventilated to maintain a PaCO_2 of 35 to 45 mm Hg. Sodium bicarbonate was administered throughout the procedure to correct any base deficit and maintain normal pH. NaCl, 0.9%, was administered to maintain a pulmonary capillary wedge pressure (PCWP) of 5 to 10 mm Hg except during the periods of aortic cross-clamping.

The left femoral and right carotid arteries were catheterized with tygon tubing (inner diameter, 0.04 mm) for simultaneous withdrawal of arterial samples during microsphere injection. Arterial blood pressure was measured with a Statham P23 Db transducer (Gould, Akron, OH) connected to a catheter inserted into the right carotid artery. A pulmonary artery catheter was inserted via the right internal jugular vein to monitor pulmonary artery pressure (PAP) and PCWP. CO was determined in triplicate at each measurement point by thermodilution using 10 mL of iced saline injected into the right atrium. A Millar high-fidelity micromanometer catheter (model PC350, Houston, TX) was placed via the left carotid artery retrograde into the LV to measure LV pressures. The LV pressure signal was differentiated to continuously measure dP/dt.

A left thoracotomy was performed through the fifth intercostal space and the heart was suspended in a pericardial cradle. A Tygon catheter was placed in the left atrium for measurement of left atrial pressure (LAP) and for injection of microspheres. The proximal left circumflex coronary artery (LCA) was dissected free and an electromagnetic flow probe (Pulsed-Logic Flow Meter, model BL610, Harvard Apparatus Co, South Natick, MA) was placed around it to measure coronary blood flow. A plastic screw clamp placed distal to the flow probe was used to narrow the coronary artery and induce a critical stenosis. A silk ligature was placed around the circumflex artery to produce intermittent 5-second occlusions of the LCA that, when released, resulted in a reactive hyperemic response (Fig 1). Critical stenosis was defined as the degree of LCA narrowing that eliminated the reactive hyperemic response to a 5-second total occlusion without altering mean coronary blood flow at rest.¹⁷

Regional myocardial blood flow (MBF) was measured with tracer-labeled microspheres (15- μm in diameter; New England Nuclear, Billerica, MA) using the reference withdrawal method.²⁰ Four injections were made in each experiment, using one of six available isotopes (^{141}Ce , ^{113}Sn , ^{51}Cr , ^{103}Ru , ^{95}Nb , ^{46}Sc), chosen at random for each flow determination. Adequate dispersal of microspheres in their suspension (1 to 2 million microspheres per injection) was achieved by sonication for 30 minutes and vortex agitation for 5 minutes prior to injection into the left atrium.

Reference arterial samples were obtained simultaneously from both femoral and carotid arteries at a constant rate (7.0 mL/min) with a Harvard withdrawal pump; withdrawals were initiated before microsphere injection and completed 2 minutes after injection.

At the end of the experiments, the dogs were killed with IV KCl. The heart was removed and placed in formalin prior to sectioning. Multiple full-thickness sections were obtained in a standardized fashion around complete rings of the LV. Each block of tissue was divided into three sections of approximately equal thickness from endocardium to epicardium. The papillary muscles were discarded. The tissue samples were weighed and placed in counting vials for assay of radioactivity in a gamma scintillation counter (model 1185, GammaTrac, Elk Grove Village, IL). After correcting the counts in each tissue sample for background and overlapping counts with simultaneous equations, blood flow was calculated with the equation²⁰:

$$Q_m = (C_m \times Q_r) / C_r$$

where Q_m , MBF in mL/min; C_m , counts/min in tissue samples; Q_r , withdrawal rate of the reference arterial sample in mL/min; and C_r , counts/min in the reference arterial sample. Tissue flow (mL/min/g) was calculated by dividing flow by the weight of the appropriate sample. Background and overlap corrections and blood flow calculations were performed on an Apple IIe microcomputer (Cupertino, CA). To standardize the data analysis, the area of myocardium at the insertion of the posterior papillary muscle (perfused by the circumflex artery) was designated as the area at risk of ischemia, and the anterior wall myocardium (perfused by the left anterior descending coronary artery) was designated as normal.

Hemodynamic parameters were recorded during each experiment on a six-channel recorder (model 2600, Gould). Variables analyzed included MAP, mean PAP (mPAP), CO, heart rate (HR), LAP, systemic and pulmonary vascular resistance (SVR, PVR), LV dP/dt, and regional MBF. Hemodynamic and MBF data were analyzed at four time periods (control, control clamp, halothane or isoflurane, and halothane-clamp or isoflurane-clamp). In two dogs receiving halothane and in two dogs receiving isoflurane, the order of interventions was reversed and these dogs were analyzed separately to determine whether order of intervention altered the response to the intervention. No such influence was noted; therefore, all halothane-treated dogs and all isoflurane-treated dogs were analyzed in their respective groups. Statistical analysis was performed using paired *t* tests between groups and

Student's *t* test within groups, and because multiple comparisons were performed, the Bonferroni inequality adjustment was used to correct the acceptable α level for the number of comparisons.⁵ A probability level of $P < 0.05$ (appropriately corrected with the Bonferroni inequality adjustment) was considered statistically significant.

Thirty minutes were allowed for the dog to stabilize after completion of instrumentation. While recording control hemodynamic parameters, a control injection of microspheres was performed (CON). The descending thoracic aorta was then totally occluded just above the diaphragm with a nontraumatic vascular clamp. Following stabilization of blood pressure and LAP (5 to 10 minutes after application of clamp), control-clamping hemodynamic measurements were performed and a second microsphere injection was made (CON CX). The vascular clamp was removed gradually to prevent declamping hypotension and 15 minutes were allowed for hemodynamic parameters to return to preclamping values (CO, HR, LAP, and MAP). The dog was then randomly assigned to receive halothane, 0.75% end-tidal concentration ($n = 11$), or isoflurane 1.25% end-tidal concentration ($n = 11$), as confirmed by mass spectrometry. After a stable end-tidal concentration of inhaled agent was achieved (20 to 30 minutes), a third injection of microspheres was performed while recording hemodynamic measurements (ANES). The thoracic aorta was then occluded as previously described, 5 to 10 minutes permitted for stabilization, and a fourth set of hemodynamic measurements and microsphere injection performed (ANES CX). Following completion of all data collection, the dog was killed with an injection of KCl, and the heart and kidneys were removed for determination of blood flows.

RESULTS

Hemodynamic results are presented in Figs 2 to 5 and in Table 1. Mean arterial pressure (MAP) was lower during halothane and isoflurane when compared with control, and was lower during both halothane clamp and isoflurane clamp than during control clamp. MAP was not different with halothane anesthesia when compared with isoflurane anesthesia, either preclamp or during aortic clamping. Clamping of the supraceliac aorta caused a significant increase in MAP whether at control clamp, halothane clamp, or isoflurane clamp, and the magnitude of the increase in MAP was the same under all conditions. As

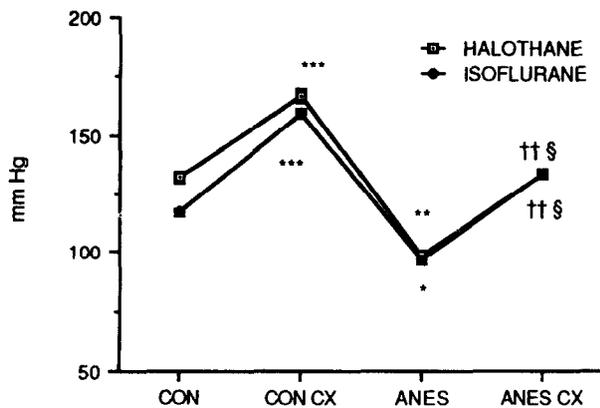


Fig 2. Changes in mean aortic pressure associated with aortic clamping in dogs receiving halothane ($n = 11$) and in dogs receiving isoflurane ($n = 11$). $*P \leq 0.05$, $**P \leq 0.01$, $***P \leq 0.001$ v CON; $\dagger\dagger P \leq 0.001$ v ANES; $\S P \leq 0.01$ v CON CX. Values are given as mean \pm SEM.

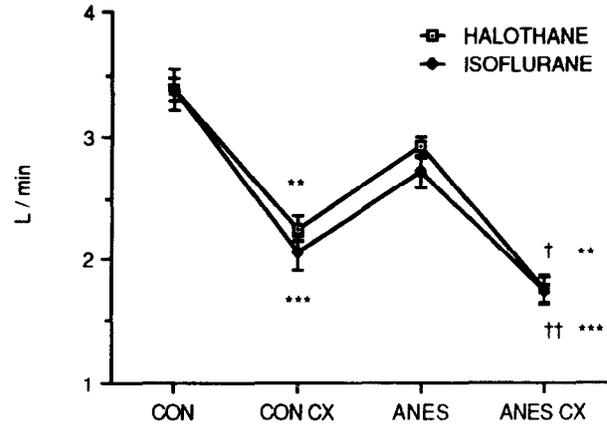


Fig 3. Alterations in CO associated with aortic clamping in dogs receiving halothane ($n = 11$) and in dogs receiving isoflurane ($n = 11$). $*P \leq 0.01$, $**P \leq 0.001$ v CON; $\dagger P \leq 0.01$, $\dagger\dagger P \leq 0.001$ v ANES. Values are given as mean \pm SEM.

illustrated in Fig 2, actual MAP post-aortic clamping was lower with halothane and isoflurane, but this lower MAP simply reflected a lower baseline MAP prior to aortic clamping and was not due to an alteration of the hemodynamic response to aortic clamping by halothane or isoflurane. Indeed, the hemodynamic response in MAP to aortic clamping was the same when halothane was compared with isoflurane. The increase in SVR associated with aortic clamping was the same during control-clamp, halothane-clamp, and isoflurane-clamp periods. There was no change in SVR associated with halothane or isoflurane anesthesia when compared either with control or with each other, and no difference in SVR between the anesthetics at aortic clamping.

CO (Fig 3) was not altered during either halothane or isoflurane alone when compared with control, but was adversely affected by all periods of aortic clamping. The decrease in CO associated with aortic clamping was the same for control clamp, halothane clamp, and isoflurane clamp. LAP, as shown in Fig 4, was not changed from

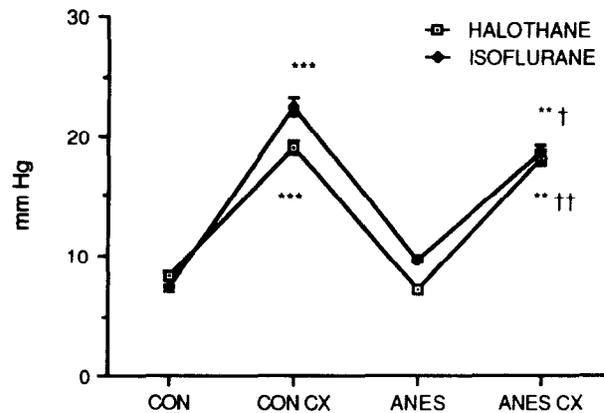


Fig 4. Changes in LAP associated with aortic clamping in dogs receiving halothane ($n = 11$) and in dogs receiving isoflurane ($n = 11$). $***P \leq 0.001$ v CON; $\dagger P \leq 0.01$, $\dagger\dagger P \leq 0.001$ v ANES. Values are given as mean \pm SEM.

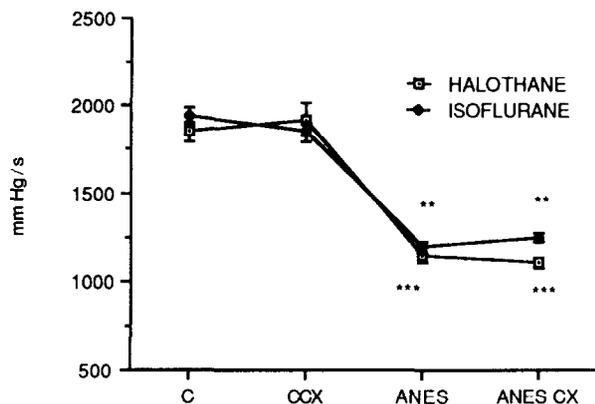


Fig 5. Changes in dP/dt associated with aortic clamping in dogs receiving halothane ($n = 11$) and in dogs receiving isoflurane ($n = 11$). ** $P \leq 0.01$, *** $P \leq 0.001$ v CON. Values are given as mean \pm SEM.

control by either halothane or isoflurane anesthesia. Aortic clamping caused a significant, equivalent increase in LAP at control clamp, halothane clamp, and isoflurane clamp. The data on the first derivative of LV pressure are shown in Fig 5. No change was found in dP/dt preclamp to postclamp at any condition (control, halothane, or isoflurane), but a significant, equivalent decrease from control was found with both halothane and isoflurane. There was no further change in dP/dt associated with aortic clamping when halothane clamp or isoflurane clamp was compared with halothane or isoflurane. There were minimal changes in HR, and although some may have achieved statistical significance, there were no physiologically significant changes.

Regional MBF results are shown in Fig 6 and Table 2; CIRC refers to myocardium in the region supplied by the narrowed circumflex artery and, thus, is the area at risk to develop ischemia (AT RISK); LAD refers to myocardium supplied by the unaffected left anterior descending artery and represents normal myocardium (NORMAL). MBF in the NORMAL zone (endocardium and epicardium) tended to be greater during isoflurane anesthesia than during halothane anesthesia when analyzed using a Student's t

test; however, this difference was not significant once the Bonferroni correction for multiple comparisons was applied. No difference in MBF was noted in either the NORMAL or AT RISK region during either anesthetic when compared with control flow. There were no differences in total flow or in flow distribution during aortic clamping among control, halothane, or isoflurane. No alteration in MBF was noted transmurally. The endocardial:epicardial (Endo:Epi) ratio as shown in Fig 7 was greater than 1.0 in both regions at all measurement periods. There was no change in the Endo:Epi ratio observed at control clamp, halothane clamp, or isoflurane clamp, or the Endo:Epi ratio between isoflurane and halothane when compared with each other or control.

DISCUSSION

The most readily apparent conclusion to be drawn from the hemodynamic results is that halothane and isoflurane at 1 MAC appear to have identical effects on MAP, SVR, CO, LAP, and dP/dt prior to or during high aortic clamping. In this model, there was no advantage of either anesthetic over the other or of either anesthetic over pentobarbital by itself. Although a lower MAP was found during supraceliac clamping with halothane and isoflurane anesthesia, this lower MAP cannot be interpreted to indicate better myocardial performance than that observed with pentobarbital anesthesia alone. The elevations of SVR and LAP associated with aortic clamping were not in any way attenuated with either isoflurane or halothane anesthesia. CO decreased similarly at control-clamp, halothane-clamp, and isoflurane-clamp periods. In a clinical setting, reliance on a volatile agent such as halothane or isoflurane to lower MAP during high aortic clamping may provide a false sense of security where a "normal" MAP masks a significant deterioration in CO and a dangerous increase in LAP. It is still controversial whether every patient undergoing aortic clamping requires monitoring with a pulmonary artery catheter, and in those cases done without the benefit of such a catheter, assessment of myocardial function is primarily based on MAP. Although a statement cannot be made as to the necessity of pulmonary arterial monitoring in every case

Table 1. Hemodynamic Responses to Aortic Clamping

	MAP (mm Hg)	LAP (mm Hg)	CO (L/min)	SVR (dyne \cdot s \cdot cm $^{-5}$)	dP/dt (mm Hg/s)	HR (beats/min)
CON	131.70 \pm 2.4	8.3 \pm 0.3	3.38 \pm 0.09	3,320 \pm 104	1,972 \pm 57	116 \pm 1.58
CON CX	166.80 \pm 2.9*	19.0 \pm 0.6*	2.25 \pm 0.10†	6,952 \pm 241*	1,999 \pm 81	119 \pm 1.90
HAL	98.90 \pm 1.6*	7.1 \pm 0.2	2.91 \pm 0.09	2,947 \pm 106	1,180 \pm 31*†	106 \pm 1.24§
HAL CX	132.70 \pm 1.5†‡	18.2 \pm 0.7*†	1.76 \pm 0.11*†	7,296 \pm 282*†	1,162 \pm 42*†	113 \pm 1.60
CON	116.70 \pm 1.1	7.3 \pm 0.2	3.39 \pm 0.17	3,312 \pm 131	1,936 \pm 49	116 \pm 2.40
CON CX	159.20 \pm 1.8*	22.5 \pm 0.7*	2.06 \pm 0.14*	8,505 \pm 403*	1,849 \pm 51	115 \pm 2.60
ISO	96.36 \pm 1.8§	9.7 \pm 0.4	2.71 \pm 0.13	3,334 \pm 127	1,195 \pm 31*†	110 \pm 1.52
ISO CX	132.60 \pm 1.5†‡	18.6 \pm 0.6*†	1.75 \pm 0.10*†	7,759 \pm 343*†	1,244 \pm 29*†	105 \pm 2.21

NOTE. All values given as mean \pm SEM.

Abbreviations: MAP, mean arterial pressure; LAP, left atrial pressure; CO, cardiac output; SVR, systemic vascular resistance; dP/dt , contractility; HR, heart rate.

* $P < 0.01$ v control.

† $P < 0.01$ v ANES.

‡ $P < 0.01$ v CON CX.

§ $P < 0.05$ v control.

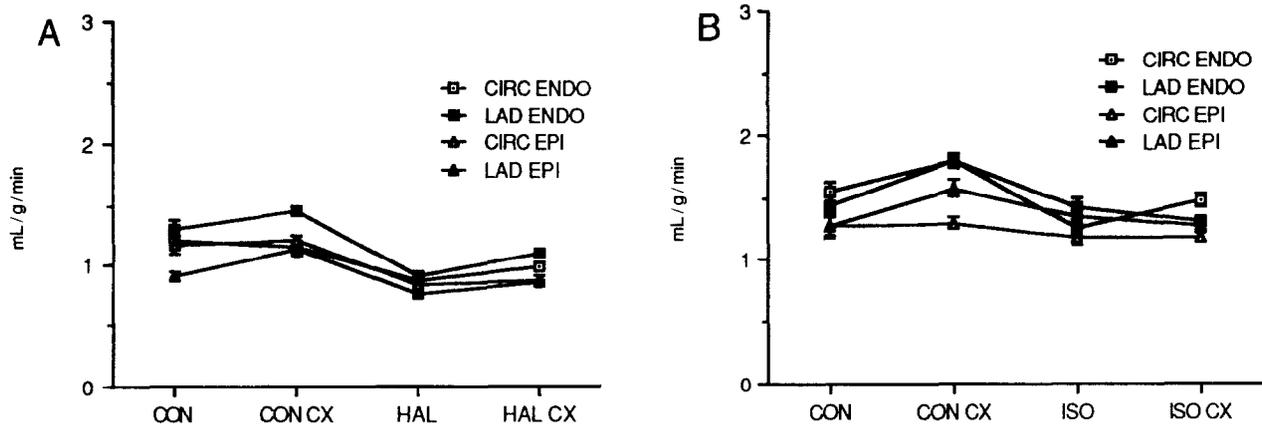


Fig 6. MBF at each intervention. CIRC represents myocardium in the region supplied by the narrowed circumflex artery and, thus, is the area at risk for development of ischemia; LAD represents myocardium supplied by the unaffected left anterior descending artery. (A) Endocardial (ENDO) and epicardial (EPI) flow in both regions in dogs receiving halothane ($n = 11$). (B) Endocardial (ENDO) and epicardial (EPI) flow in both regions in dogs receiving isoflurane ($n = 11$). Values are given as mean \pm SEM.

involving aortic clamping, the present data demonstrate that, in this model, neither halothane nor isoflurane is capable of altering the increase in SVR and LAP and the deterioration in myocardial performance that may occur with supracoeliac aortic clamping.

The acute hemodynamic changes associated with supracoeliac aortic clamping fit the description given by Ross (based on initial work by Guyton) of afterload mismatch.^{21,22} Briefly, in any normal heart, there is an optimum match between LV filling volume/pressure (preload) and afterload. As afterload increases, incomplete emptying of the ventricle occurs, filling volume/pressure increases, and fiber length increases, allowing myocardial performance (measured in this study by CO) to continue unchanged. Preload reserve is additional myocardial work that can be recruited by increases in fiber length. The limits of preload reserve are defined both by available venous return (determined by circulating blood volume, vascular tone) and by the point in any given heart where a further increase in fiber length leads to decreasing myocardial performance (descending limb of the Frank-Starling curve). If a given increase in afterload is not matched by an appropriate increase in preload, or if the preload reserve is exhausted, an afterload mismatch is created. The immediate consequence of such a mismatch is a decrease in stroke volume and, thus, a

decrease in CO. Based on these results that show a dramatic increase in LAP and a decrease in CO during supracoeliac clamping, it seems that such an afterload mismatch exists, due predominantly to exhaustion of preload reserve. In a canine model of aortic occlusion similar to the present one, Stokland et al²³ found that concurrent occlusion of the aorta and inferior vena cava effectively prevented any increase in preload, but caused CO to fall much further than if preload was permitted to increase during aortic occlusion. All these data support the concept that preload increases compensate for increased afterload, and that afterload mismatch can rapidly develop if the preload increase is limited or inappropriately matched to afterload. Once present, afterload mismatch can be attenuated or corrected by increasing the inotropic state of the myocardium. Such an increase in the inotropic state of the heart not only increases stroke volume and CO by increasing the velocity of myocardial fiber shortening, it also returns preload reserve by reducing LV end-diastolic volume. In the present model, the dangers of halothane and isoflurane anesthesia are twofold: (1) these anesthetics do not alter the degree of afterload imposed by high aortic clamping (no change in SVR); and (2) they also reduce contractility (dp/dt) of the myocardium, potentially accentuating the mismatch between preload and afterload.

Table 2. Regional Myocardial Blood Flow During Aortic Clamping

	Endocardium (mL/g/min)		Epicardium (mL/g/min)	
	LAD	CIRC	LAD	CIRC
CON	1.310 \pm 0.062	1.210 \pm 0.056	0.920 \pm 0.036	1.180 \pm 0.083
CON CX	1.450 \pm 0.036	1.160 \pm 0.045	1.130 \pm 0.044	1.210 \pm 0.045
HAL	0.922 \pm 0.026	0.870 \pm 0.020	0.766 \pm 0.022	0.839 \pm 0.029
HAL CX	1.098 \pm 0.036	0.990 \pm 0.023	0.850 \pm 0.030	0.880 \pm 0.039
CON	1.440 \pm 0.064	1.540 \pm 0.080	1.270 \pm 0.084	1.260 \pm 0.077
CON CX	1.790 \pm 0.053	1.790 \pm 0.052	1.570 \pm 0.062	1.290 \pm 0.050
ISO	1.420 \pm 0.062	1.240 \pm 0.054	1.340 \pm 0.071	1.180 \pm 0.056
ISO CX	1.310 \pm 0.030	1.470 \pm 0.054	1.270 \pm 0.051	1.180 \pm 0.044

NOTE. LAD denotes myocardium supplied by the unaffected LAD artery and represents normal tissue; CIRC is that tissue supplied by the stenosed circumflex artery and represents tissue at risk. All values are given as mean \pm SEM.

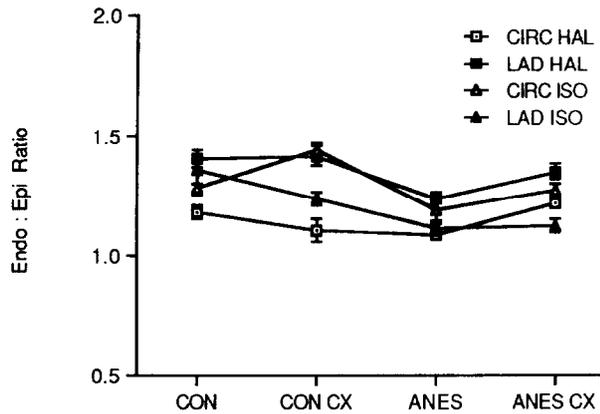


Fig 7. Transmural blood flow in dogs receiving halothane (n = 11) or isoflurane (n = 11). Note that the ratio of endocardial blood flow to epicardial blood flow is greater than 1 at all time periods and in both regions. CIRC HAL, myocardium supplied by the narrowed circumflex artery in dogs receiving halothane; LAD HAL, myocardium supplied by the unaffected LAD artery in dogs receiving halothane; CIRC ISO, myocardium supplied by the narrowed circumflex artery in dogs receiving isoflurane; LAD ISO, myocardium supplied by the unaffected LAD artery in dogs receiving isoflurane. Values are given as mean \pm SEM.

Isoflurane is generally believed to cause a dose-dependent decrease in SVR that preserves CO. The first such evidence of isoflurane's effect on SVR came from studies in spontaneously breathing, healthy human volunteers, without surgical stimulation.²⁴ Whereas the evidence that isoflurane does act as a dose-dependent peripheral vasodilator is clear, such an effect may not be apparent at the 1 MAC concentration when surgical stimulation is present, as in this model. Studies in which isoflurane at concentrations of 0.5% to 2% did not reduce SVR have included work done on lambs,²⁵ hypertensive rats,²⁶ dogs,^{27,28} and humans.^{29,30} Based on the present data and similar data from other laboratories, the clinical practitioner should not rely on isoflurane at this concentration to invariably decrease SVR, especially when the elevated vascular resistance is due to aortic clamping.

No alterations in MBF or its transmural distribution during either halothane or isoflurane anesthesia were found that could be construed as being likely to impair

myocardial performance. Certainly, the deleterious effects of aortic clamping on CO cannot be attributed to a redistribution in blood flow caused by either of these volatile anesthetics. No difference in MBF was noted between the region supplied by a vessel with a critical stenosis versus that supplied by a normal vessel. However, this experiment was not designed to specifically investigate coronary steal, and did not include either of the key features felt to be important in the genesis of redistribution. Although there is some indication in the results that isoflurane may act as a coronary artery vasodilator, the vasodilation did not cause maldistribution of blood flow in this model with a single stenotic coronary artery. Although there was no evidence of blood flow redistribution, there was some indication of an increase in total LV blood flow similar to that demonstrated by Carson et al.³¹ Different results may have been obtained had the coronary stenosis in this model been more severe. Not addressed by this experimental protocol is the question of whether any degree of myocardial ischemia was present, regionally or globally. Wall motion or segmental wall thickening, or epicardial electrocardiographic tracings were not monitored. In this model, aortic cross-clamping elevated both mean aortic pressure and LV end-diastolic pressure, but it cannot be stated that in any given region (subendocardium *v* epicardium, normal *v* at risk) myocardial oxygen supply did or did not match oxygen demand. Nonetheless, because all measured hemodynamic parameters and myocardial blood flow determinants were equivalent among control, halothane, and isoflurane, it seems reasonable to conclude that any imbalance between myocardial oxygen supply and demand would have been equivalent with each agent.

In conclusion, it was found that supraceliac aortic clamping in dogs with a critical coronary stenosis resulted in similar hemodynamic consequences during both halothane and isoflurane anesthesia, and that both volatile agents may potentiate an afterload-preload mismatch that results from aortic clamping. Isoflurane did not alter SVR, nor result in better preservation of CO, when compared with either halothane or pentobarbital. In addition, no evidence of regional or transmural alterations in MBF was found in comparing isoflurane with halothane or pentobarbital either prior to or during high aortic cross-clamping.

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