Forearm Venous and Arterial Responses to Halothane and Cyclopropane

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Forearm venous compliance, venous and arterial pressures, heart rate, and forearm blood flow were measured in adult patients before and at two levels of anesthesia with cyclopropane and halothane. Subjects were not premedicated and observations were made before operation. Cyclopropane anesthesia was accompanied by increases in arterial and venous pressure, and by decreases in forearm venous compliance and blood flow. Halothane anesthesia was associated with decreases in arterial pressure and slight increases in venous compliance, venous pressure, heart rate, and forearm blood flow. The changes in arterial and venous pressure, heart rate and forearm flow observed with both agents are similar to observations reported previously. The decrease in forearm venous complianec found with cyclopropane is attributed to an increase in tone in venous smooth muscle.

VENOUS pressure depends upon the volume of blood within the veins and the compliance of the venous walls. Anesthesia with cyclopropane is accompanied by a reduction in blood volume and an increase in venous pressure.[1, 2] During halothane anesthesia blood volume remains unchanged and changes in venous pressure are small and directionally inconsistent.[3, 4] These facts suggest that cyclopropane and halothane have different effects on veins and that the increase in venous pressure with cyclopane is associated with a decrease in venous compliance. The experiments to be reported here were done to study the effects of cyclopropane and halothane anesthesia on the pressure-volume characteristics of the veins of the forearm.

Methods

The subjects were nine generally healthy patients without cardiovascular disease. Their ages ranged from 21 to 58 years. Preanesthetic drugs were withheld. Studies were done in the operating room immediately before elective surgical procedures. Observations were made with subjects lying supine on an operating table. Room temperature was 74° F.

Polyethylene catheters for measuring pressures were inserted through needles into the antecubital vein of the slightly dependent left arm and into the right femoral artery. The right forearm was enclosed in a water plethysmograph used for measuring venous compliance. Venous and arterial pressures were measured with Statham strain gauges. Water level in the plethysmograph was measured with a float and displacement transducer.* Arterial pressure pulse signals were fed into an integrating tachometer to obtain heart rate. Pressures, heart rate and water level were recorded with a Sanborn direct writing oscillograph. Blood gases and *p*H were measured on arterial blood with Instrumentation Laboratories electrodes.

The method for obtaining venous pressure-volume curves has been described elsewhere.[5, 6] A brief description is included here. The forearm is enclosed in a plethysmograph and water is added so that the pressure it exerts on the

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Supported by research career program awards HE-K6-4626 and HE-K3-17013 from the National Heart Institute and research grants from the U. S. Public Health Service (HE-02644), the Iowa Thoracic Society and the Iowa Heart Association.

* Manufactured by the Sanborn Company, Waltham, Massachusetts.

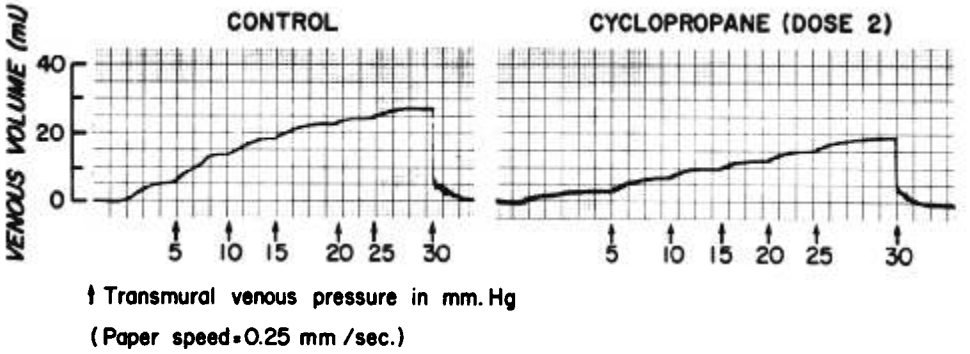

FIG. 1. Forearm volume records obtained during a control period and during anesthesia with cyclopropane. The arrows along the time axis represent levels of transmural pressure in forearm veins produced by inflation of the proximal cuff. The small volumes at each transmural pressure during cyclopropane anesthesia indicate reduced compliance of the veins. The decreased slope of the volume record as the veins fill during anesthesia represents reduced forearm blood flow.

arm is greater than venous pressure but less than diastolic arterial pressure. The arterial inflow drives the pressure within the veins to a level slightly greater than the external water pressure. The difference between the pressure within the veins and the pressure surrounding them is the distending or transmural pressure. Under resting conditions and under the circumstances described here, transmural pressure is low. It ranges from about 0.5 to 2.0 mm. of mercury and is constant and reproducible in a given subject.[6] The volume of blood in the vessels of the extremity at this low transmural pressure is about 1.3 ml./100 ml. of tissue.[7] Under resting conditions this volume also is constant and reproducible in a given subject; it is called the "baseline" volume. Increases in volume in response to application of a congesting cuff take place primarily in vessels whose resting pressures are less than 10 mm. of mercury[7]. The origin of the venous pressure-volume curves is the "baseline" volume and the low transmural venous pressure which is present when external water pressure is greater than natural venous pressure. Since the "baseline" volume and pressure are constant they are regarded for practical purposes as zero. Venous pressure-volume curves may be obtained by increasing transmural pressure from "zero" to 30 mm. of mercury in increments of 5 mm. of mercury by inflating a cuff on the arm proximal to the plethysmograph. Each increment of pressure is held constant until forearm volume becomes stable before adding the next increment of pressure to the cuff (fig. 1). In previous work using this method,[8] curves were constructed by plotting each level of volume in ml./100 ml. of forearm against its corresponding level of transmural

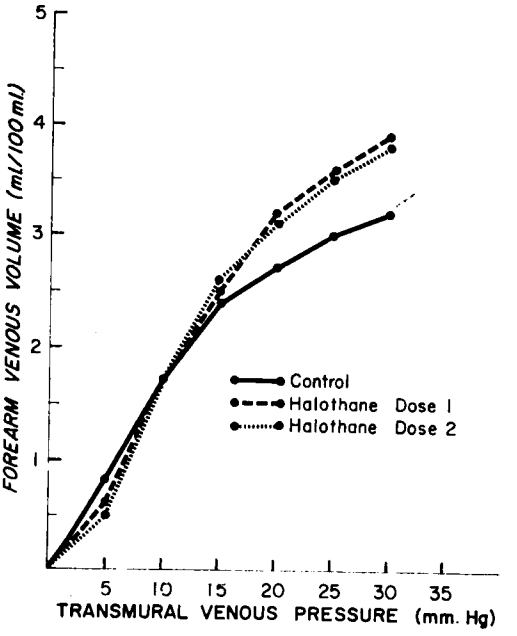

FIG. 2. Each level of forearm volume in milliliters per 100 ml. of tissue has been plotted against its corresponding level of transmural pressure. In this experiment the pressure-volume curves shifted slightly toward the volume axis during halothane anesthesia suggesting increased venous compliance. These changes with halothane were small and not significant statistically.

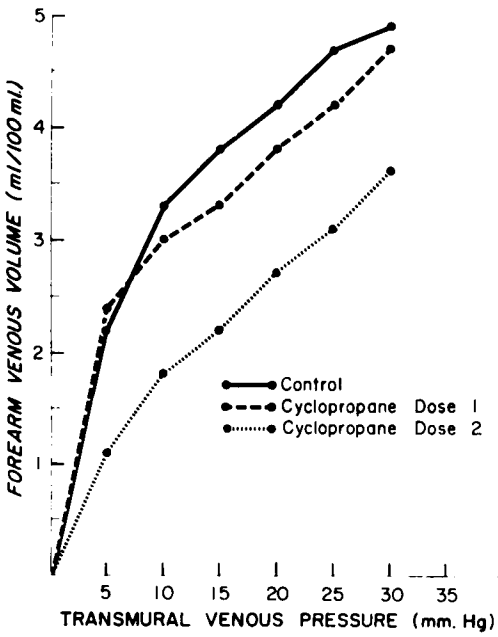

FIG. 3. Forearm venous pressure-volume curves obtained during a control period and during anesthesia with cyclopropane. Shift of the curves toward the pressure axis during anesthesia indicates decreased venous compliance.

pressure (figs. 2 and 3). These curves are convex toward the volume axis. If the veins lose tone and compliance increases the curve falls nearer the volume axis. If tone increases and compliance decreases the curve falls nearer the pressure axis. The final point on the curve, the venous volume at a transmural pressure of 30 mm. of mercury is an index of venous complinance. A high value is associated with a curve of increased compliance, a low value with a curve of decreased compliance. In many of the experiments reported here, transmural pressure was increased to 30 mm. of mercury with a single inflation of the cuff. Pressure was then held constant until forearm volume became stable or was increasing at only a negligible rate. The volume at a transmural pressure of 30 mm. of mercury is the same with stepwise or single inflation of the cuff. The values for venous compliance which are reported in the tables are stable volumes present at a transmural pressure of 30 mm. of mercury.

The initial slope of the volume record as the veins fill is an index of the rate of blood flow into the forearm (fig. 1.). The actual rate of flow into the forearm was not calculated. Directional changes were determined from changes in the slope of the volume record; they are identified in the tables by arrows.

Control observations were made with subjects awake after they had been resting for at least 30 minutes with all apparatus connected. Anesthesia was then administered utilizing standard machines with large CO_2 absorbers. Five subjects received halothane-oxygen from a halothane vaporizer compensated for flow and temperature. A total flow of six liters of oxygen per minute was employed. Four subjects received cyclopropane-oxygen in a closed system after a five-minute period of partial dennitrogenation. A steady level of "light" clinical anesthesia as judged by pupillary and eyeball responses, blood pressure and pulse rate, capillary refill, and rate and depth of respiration was achieved with nearly constant concentrations of inspired gas. Experimental observations were made after 20 to 30 minutes at this level of depression (dose 1). The concentration of the agent was then increased (dose 2). Observations were repeated after 20 to 30 minutes of anesthesia at the higher dose.

Respiration was controlled when necessary to maintain arterial CO_2 tension near normal. The inspired concentration of halothane ranged from 1 to 2 per cent for the low dose and from 2 to 3.5 per cent for the higher dose. The inspired cyclopropane concentration ranged from 20 to 30 per cent for the low dose and 26 to 38 per cent for the higher dose.

Results

There were significant decreases in mean arterial pressure during anesthesia with halothane (table 1). The changes in heart rate, venous pressure and venous compliance were small. There appeared to be a tendency for both venous compliance (table 1, fig. 1) and venous pressure to increase but the changes were small and not significant statistically. Forearm blood flow decreased at the low dose of halothane but increased with the high dose.

There were marked decreases in venous compliance with cyclopropane (tables 2, figs. 1 and 3); these changes were accompanied by

TABLE 1. Responses to Halothane

Subject	Age Yrs.	VV_{30} ml./100 ml.			VP mm. Hg			MAP mm. Hg			HR beats/min.			ΔBF	
		C	D_1	D	C	D_1	D_2	C	D_1	D_2	C	D_1	D_2	D_1	D_2
F. M.	58	3.4	3.4	4.1	4.3	5.5	7.0	95	75	65	60	70	60	→	↑
B. H.	43	5.8	6.0	6.0	5.3	5.8	5.8	100	85	70	80	75	75	↓	↑
E. A.	50	4.5	4.6	4.6	11.5	12.0	12.5	70	65	70	75	72	72	↓	↑
W. S.	41	3.5	3.9	3.8	9.0	11.5	12.0	85	65	60	68	72	72	↓	↑
D. L.	38	4.2	4.2	4.3	9.0	9.0	9.0	90	80	70	81	80	90	↓	↑
Mean		4.3	4.4	4.6	7.8	8.8	9.3	88	74	67	73	74	74		
Mean difference from C			0.14	0.28		0.94	1.44		14.0	21.0		1.0	1.0		
Standard error			0.077	0.110		0.434	0.598		2.915	5.568		2.702	2.510		
Probability			>0.1	>0.05		>0.05	>0.05		<0.01	<0.02		>0.7	>0.7		

VV_{30} refers to the venous volume at a transmural venous pressure of 30 mm. of mercury. VP is venous pressure. MAP is mean arterial pressure. HF is heart rate. ΔBF indicates the direction of change in forearm blood flow from the control during anesthesia. ↑ indicates an increase, → indicates no change, and ↓ indicates a decrease. C represents observations made during control periods. D_1 and D_2 refer to observations made at dose 1 and dose 2, respectively (see text).

TABLE 2. Responses to Cyclopropane

Subject	Age Yrs.	VV_{30} ml./100 ml.			VP mm. Hg			MAP mm. Hg			HR beats/min.			ΔBF	
		C	D_1	D_2	C	D_1	D_2	C	D_1	D_2	C	D_1	D_2	D_1	D_2
M. D.	41	3.8	2.8	3.3	8.0	17.5	19.0	65	90	75	72	72	66	↓	↓
K. B.	21	5.0	4.7	3.6	7.5	10.0	12.5	65	85	75	78	66	90	↓	↓
J. S.	29	5.8	5.4	4.0	7.5	13.0	16.5	60	70	80	76	60	90	↓	↓
R. Z.	36	6.9	5.7	5.7	9.0	15.0	16.0	90	95	95	80	74	92	→	↓
Mean		5.4	4.7	4.2	8.0	13.9	16.0	70	85	81	77	68	85		
Mean difference from C			0.73	1.23		5.88	8.00		15.0	11.3		8.5	8.0		
Standard error			0.221	0.272		1.435	1.291		4.570	3.145		3.500	4.690		
Probability			<0.05	<0.05		<0.05	<0.01		<0.05	<0.05		>0.05	>0.1		

See footnotes to table 1.

large increases in venous pressure. Mean arterial pressure increased, heart rate did not change significantly, and forearm blood flow decreased.

Discussion

The observations reported here are in general agreement with the changes in venous and arterial pressure, heart rate and forearm blood flow reported by others who have investigated the hemodynamic effects of cyclopropane and halothane in man.[4, 9, 10, 11] In addition we have found that forearm venous compliance decreases significantly with cyclopropane and increases or remains unchanged with halothane. The decreased compliance with cyclopropane may explain the increase in venous pressure.

It appears that cyclopropane has a stimulating effect on the circulation similar to that seen with infusions of norepinephrine. Both cyclopropane and norepinephrine cause increases in tone of both arteries and veins. The reported observations [12] of increased sympathetic activity during cyclopropane anesthesia may explain the similarity between the responses to the two agents.

Halothane has effects on the circulation which are somewhat opposite to those of cyclopropane. Our results showed small increases in forearm venous compliance and venous pressure accompanied by significant decreases in mean arterial pressure and increases in forearm blood flow. These findings suggest depressing or dilating effects on both arteries and veins and are consistent with studies which have demonstrated no increase in circulating norepinephrine levels during halothane anesthesia in man.[12]

Summary

Observations on venous and arterial pressure, heart rate, forearm blood flow and forearm venous compliance were made at two levels of anesthesia with cyclopropane and halothane.

Halothane was associated with a decrease in arterial pressure, a tendency toward an increase in venous compliance and small and directionally inconsistent changes in venous pressure and heart rate. Forearm blood flow decreased at the lower level of anesthesia and increased with the higher level.

Cyclopropane was associated with increases in venous and arterial pressures and decreases in forearm blood flow. Heart rate did not change significantly. Venous compliance decreased. This change in compliance is attributed to an increase in tone of venous smooth muscle. It may explain the increase in venous pressure.

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