Anesthesiology
62:149–154, 1985

Cardiovascular Responses to Hemodilution and Controlled Hypotension in the Dog

J. L. Plewes, M.D., and L. E. Farhi, M.D.†*

Cardiovascular responses to acute hemodilution and controlled hypotension were studied in mongrel dogs anesthetized with halothane and paralyzed with pancuronium. Regional blood flows were determined by microsphere injections. Hemodilution to an hematocrit of 23% was produced by removal of whole blood and simultaneous infusion of Ringer's lactate solution. Subsequently, hypotension to a mean arterial pressure of 55 mmHg was produced for 90 min by intravenous infusion of trimethaphan. The hypotension resulted entirely from a 55% decrease in total peripheral resistance. Thirty minutes after initiation of controlled hypotension, there were significant increases in blood flow to the brain, liver, skeletal muscles, and diaphragm. However, at 30 min, calculated oxygen delivery had decreased to brain (−16%), renal cortex (−51%), heart (−45%), and retina (−44%). By 90 min, retinal, adrenal, and renal cortical blood flows were decreased significantly relative to control, and cerebral blood flows had returned to control levels. Absence of changes in acid–base status during the period of hemodilution and hypotension may indicate that whole body oxygen delivery was maintained at adequate levels. However, major decreases in calculated oxygen delivery after 90 min to critical tissue beds such as renal cortex (−67%) and retina (−78%) indicate that extension of the procedure past 30 min may involve risks that are not warranted by the benefits. (Key words: Anesthetic techniques: controlled hypotension; trimethaphan. Blood: hemodilution. Oxygen: delivery.)

THE COSTS AND HAZARDS associated with homologous blood transfusions have made it desirable to develop new techniques that will aid in minimizing blood loss during surgery. Such techniques have included acute preoperative hemodilution[1,2] and production of controlled hypotension using drugs such as sodium nitroprusside or trimethaphan camsylate.[3,4] Recently, anesthesiologists have used a combination of these two techniques, to produce a hemodiluted, hypotensive state.[5] During such a state in which oxygen-carrying capacity is decreased by the removal of erythrocytes, and in which perfusion pressures are depressed, maintenance of oxygen delivery to the tissues may be at risk. In this article we report the effects, in dogs, of 90 min of hemodilution and controlled hypotension on the cardiovascular system, including the distribution of peripheral blood flow.

* Assistant Professor of Anesthesiology and Physiology.

† Professor of Physiology.

Received from the Departments of Anesthesiology and Physiology, State University of New York at Buffalo, Buffalo, New York. Accepted for publication August 24, 1984. Supported by NHLB Grant #HL-23190 and by the Henry and Bertha Buswell Foundation.

Address reprint request to Dr. Plewes: Department of Anesthesiology, The University of Oklahoma, P. O. Box 53188, South Pavilion, 4th Floor, Oklahoma City, OK 73152.

Methods

Mongrel dogs of either sex weighing between 14 and 20 kg were used for this study. Each dog was anesthetized with thiopental sodium (30 mg/kg, iv), placed in the supine position, intubated with a cuffed endotracheal tube, and mechanically ventilated to achieve a Pa_{CO_2} of approximately 28 mmHg. Anesthesia was maintained with 1.2% halothane in oxygen delivered with a Fluotec III® vaporizer. End-tidal halothane concentrations were monitored with an Analytics Systems Company Fluothane Monitor®.

Catheters were inserted into a peripheral vein to allow infusion of maintenance fluids (Ringer's lactate, 4 $ml \cdot kg^{-1} \cdot h^{-1}$) and drugs and into the descending aorta via the right femoral artery. A Swan-Ganz® thermodilution catheter was inserted into the pulmonary artery via the external jugular vein in order to measure both cardiac output and pulmonary artery pressure. A #7F Cordis® catheter was placed with its tip in the left ventricle via the left femoral artery in order to measure left ventricular pressures. Peak dP/dt determinations were made from measurements of the left ventricular pressure trace obtained at 5 ms intervals with a microcomputer equipped with analog-to-digital converters with an accuracy of 0.1%.

After insertion of the catheters, the animal was allowed to inspire 1.2% halothane in oxygen for about 90 min, during which time we estimate the alveolar concentration reached approximately 70–75% of the inspired value. Vascular pressures were measured with Statham strain-gauge manometers and compared with a zero reference level opposite the level of the right atrium. Temperature was measured with a rectal thermometer and with the thermistor in the Swan–Ganz® catheter.

Distribution of peripheral blood flows were determined using 15-μm polystyrene spheres (New England Nuclear) labeled with Gd-153, Ru-103, Sn-113, Nb-95, or Sc-46, and suspended in a 0.9% NaCl solution containing 0.01% Tween-80® to prevent sphere aggregation. The spheres had been measured to determine true diameters (13.5 ± 2 μm SD) and variability and to ensure the absence of nonspherical spheres. A sample of each type of sphere was counted to determine mean radioactivity levels in counts/min. Approximately one million spheres were suspended in 10 ml of the dog's blood and injected into the left ventricle, and the catheter was flushed with 10 ml Ringer's lactate. Blood

was withdrawn continuously from the descending aorta at a constant rate (2.3 ml · min^{-1}) from about 10 s before and for about 3 min after each injection. Radioactivity levels in these blood samples allowed us to calculate the blood flow to specific organs using the equation

organ flow

= organ activity(CPM)*withdrawal rate/WSA(CPM)

where WSA(CPM) is the number of counts per minute in the sample withdrawn at constant rate (withdrawal rate) from the aorta, and organ activity(CPM) is the counts per min in the specific organ.

At the end of the period of stabilization, the cardiac output was measured by determining the mean thermodilution response to several serial injections of iced 5% glucose in water. Pressure data and blood gases (arterial and pulmonary arterial) were obtained during this time period, and the first injection of radioactive labeled microspheres was made. Control conditions were maintained for 60 min, and the measurements were repeated.

After the control period, hemodilution was accomplished by collecting arterial blood from the femoral catheter in a heparinized graduated cylinder. Ringer's lactate, at body temperature, to which 2 mEq/l of $MgSO_4$ had been added, was infused in a vein, in a volume equal to three times that of the whole blood removed. We calculated from the following empiric formulae the volume of whole blood that had to be removed to decrease the hematocrit to the desired level of about 20%;

$$EBV\ (ml) = 80\ (ml\ blood/kg) * body\ weight\ (kg)$$

$$ERCV = Hct.\ (\%) * EBV$$

$$ERCV_{(Control)} = Hct.\ (\%) * EBV$$

$$ERCV_{(20)} = 0.2 * EBV$$

$$red\ cell\ volume\ to\ remove = ERCV_{(Control)} - ERCV_{(20)}$$

$$blood\ volume\ to\ remove = 3 * red\ cell\ volume\ to\ remove$$

where:

EBV = estimated blood volume (ml)
$ERCV_{(control)}$ = estimated red blood cell volume during the control period
$ERCV_{(20)}$ = estimated red blood cell volume at Hct. = 20%

After the hemodilution, controlled hypotension to a mean arterial pressure of 55 mmHg was produced, with the use of an intravenous infusion of trimethaphan (0.5 mg/ml). The animals were studied 30 min after the desired mean arterial pressure had been reached and again 60 min later.

Following the 90 min of hypotension and hemodilution, the trimethaphan infusion was stopped, and the whole blood removed during hemodilution was reinfused. Diuresis was produced with 10 mg furosemide, and 60 min later the animals were studied again.

At the end of the experiment, the animal was killed by injection of saturated KCl solution. The brain, heart, eyes, liver, kidneys, adrenals, and portions of the duodenum, ileum, colon, pancreas, spleen, diaphragm, masseter, and triceps were removed and fixed in 10% formalin for at least four days. At that point, the organs were sectioned, weighed, and placed in plastic tubes for radioactive counting in an ND-60 well-type gamma counter and multichannel analyzer. Tissue samples were counted long enough to ensure a minimum of 10,000 counts above background. We also could ensure from the radioactivity levels that the specimens contained a minimum of 400 spheres, to minimize sampling errors.[6]

Some organs were sectioned in detail to look for any intraorgan changes in the distribution of blood flow. The renal cortex was sectioned into four concentric layers, with layer one being outermost and layer four being juxtamedullary. The brain was sectioned into numerous anatomic areas, including caudate, cerebellum, thalamus, hippocampus, pons, mesencephalon, and vermis.

Tissues with low blood flows (muscle) were measured by counting multiple larger samples. Total peripheral resistance was calculated by dividing mean perfusing blood pressure by blood flow in ml/min, assuming downstream venous pressure to be 10 mmHg.

Oxygen delivery to specific tissue beds was calculated assuming a standard oxygen dissociation curve for dog hemoglobin[7] and standard values for the physical solubility of oxygen in blood (0.023 ml O_2 · ml $blood^{-1} \cdot atm^{-1}$).

Statistical analysis was performed using the nonparametric Wilcoxon signed-ranks test, which is appropriate for matched pairs of data where the samples are related but not independent.[8,9] Probability values of less than 0.02 were considered significant.

Results

Comparison of variables and blood flows during the two control periods revealed no significant differences, so they were combined and are presented as one control group (tables 1–3).

Hemodilution resulted in a decrease in hematocrit from 43 to 23% ($P < 0.02$). Trimethaphan infusion produced a stable hypotension for the 90-min period, with mean arterial pressure of about 55 mmHg, signif-

icantly lower than the control level of 101 mmHg. Blood pressure returned to control levels (108 mmHg) after reinfusion of the blood and cessation of trimethaphan infusion (table 1).

There were no significant changes in cardiac output, so hypotension resulted entirely from a 55% decrease in calculated total peripheral resistance. There were no significant changes in heart rate, left ventricular peak dP/dt, left ventricular end-diastolic pressure (LVEDP), or mean pulmonary artery pressure. During recovery, only mean pulmonary artery pressure was different from control levels, increasing from control levels of 11.7 mmHg to 16.7 mmHg ($P < 0.02$).

There were no significant changes in body temperature, Pa_{O_2}, $P\bar{v}_{O_2}$, Pa_{CO_2}, $P\bar{v}_{CO_2}$, or pH during the experiment. Urine output was increased significantly during recovery to a mean of 28 $ml \cdot kg^{-1} \cdot h^{-1}$.

TABLE 1. Circulatory Variables Measured during the Control Period, after 30 and 90 Min of Combined Hypotension and Hemodilution (HD/HT-30 and HD/HT-90), and 60 Min after Reinfusion of the Blood and Return of Blood Pressure to Control Levels.

Variable	Control	HD/HT-30	HD/HT-90	Recovery
Cardiac output	3.69	4.05	3.45	3.40
$(l \cdot min^{-1} \cdot m^{-2})$	0.16	0.32	0.31	0.39
Heart rate	109	114	102	102
(beats/min)	4.5	3.9	3.1	9.4
Mean arterial	101	55*	56*	108
pressure	3	4	4	4
(mmHg)				
Total peripheral	0.035	0.016*	0.019*	0.043
resistance	0.002	0.002	0.003	0.006
(PRU)				
Peak dPdT	1832	1,564	1,413	1,582
$(mmHg \cdot s^{-1})$	52	104	61	67
LVEDP (mmHg)	8.1	4.7	6.2	13.4
	0.9	1.1	0.7	2.3
Mean pul. artery	11.7	10.3	10.1	16.7*
pressure	0.5	1.5	1.1	1.4
(mmHg)				
Body temp. (°C)	37.3	37.0	36.8	36.7
	0.1	0.2	0.2	0.2
Hematocrit	42.5	23.3*	23.4*	40.6
	0.8	1.0	1.0	1.5
Pa_{O_2} (mmHg)	531	454	504	512
	35	72	66	76
$P\bar{v}_{O_2}$ (mmHg)	59	53	49	62
	2	3	4	12
Pa_{CO_2} (mmHg)	29	31	29	30
	1	1	2	2
$P\bar{v}_{CO_2}$ (mmHg)	35	37	39	38
	1	2	2	2
pH	7.42	7.38	7.39	7.40
	0.01	0.01	0.02	0.03
Urine output	5.0	3.1	2.1	28.1*
$(ml \cdot kg^{-1} \cdot h^{-1})$	0.7	0.4	0.7	3.2

Values given are means and standard errors of the mean. All control values are the means of 14 observations on seven animals. All others are the means of seven observations on the seven animals.
* $P < 0.02$ compared with control.

TABLE 2. Cerebral and Retinal Blood Flows $(ml \cdot gm^{-1} \cdot min^{-1})$ Measured during the Control Period, after 30 and 90 min of Combined Hypotension and Hemodilution (HD/HT-30 and HD/HT-90) and 60 Min after Reinfusion of the Blood and Return of Blood Pressure to Control Levels.

Tissue	Control	HD/HT-30	HD/HT-90	Recovery
Brain	0.54	0.79*	0.66	0.39**
	0.03	0.09	0.06	0.05
Cortical White	0.58	0.75	0.58	0.45
	0.04	0.12	0.06	0.05
Cortical Grey	0.77	1.3	1.0	0.49
	0.08	0.2	0.1	0.07
Thalamus	0.48	0.76*	0.66*	0.42
	0.02	0.11	0.05	0.04
Caudate	0.80	1.21*	1.12*	0.70
	0.04	0.15	0.10	0.06
Cerebellum	0.46	0.65	0.52	0.32*
	0.02	0.09	0.02	0.02
Pons	0.27	0.42*	0.34*	0.21
	0.01	0.05	0.02	0.03
Mesencephalon	0.41	0.62*	0.55	0.33
	0.02	0.09	0.06	0.05
Hippocampus	0.41	0.61*	0.50	0.31
	0.02	0.08	0.04	0.04
Retina	2.6	2.0	1.0*	1.3*
	0.2	0.2	0.1	0.2

Values given are means and standard errors of the mean. All control values are the means of 14 observations on seven animals. All others are the means of observations on the seven animals.
* $P < 0.02$ compared with control.

Calculated total body oxygen delivery decreased to 58% of control at 30 min and to 71% of control at 90 min. Oxygen delivery returned to control levels after recovery (table 4).

Total cerebral blood flow increased by 46% after 30 min of hemodilution and hypotension but returned to control levels by 90 min (table 2). Calculated oxygen delivery to brain decreased to 84% of control at 30 min and to 71% of control at 90 min (table 4). Within the brain tissues, there were significant increases of about 50% in blood flow to thalamus, caudate, pons, mesencephalon, and hippocampus. These increases were sustained at 90 min in thalamus, caudate, and pons. There were no changes in the blood flow to cortical gray and white tissues or to the cerebellum.

Renal cortical blood flow in all four layers was decreased by 30–35% by 90 min of hypotension and hemodilution (table 3) ($P < 0.02$). Urine output was not changed significantly. These flows remained decreased, even during the recovery period, despite the 14-fold increase in mean urine output from 2.1 $ml \cdot kg^{-1} \cdot h^{-1}$ to 28 $ml \cdot kg^{-1} \cdot h^{-1}$. Calculated oxygen delivery to the kidney decreased to 49% of control at 30 min and to

TABLE 3. Tissue Blood Flows ($ml \cdot g^{-1} \cdot min^{-1}$) Measured During the Control Period, after 30 and 90 Min of Combined Hypotension and Hemodilution (HD/HT-30 and HD/HT-90), and 60 Min after Reinfusion of the Blood and Return of Blood Pressure to Control Levels

Tissue	Control	HD/HT-30	HD/HT-90	Recovery
Renal cortex 1 (outer cortical)	6.3 0.3	5.4 0.5	3.6* 0.3	4.8 0.5
Renal cortical Layer 2	6.7 0.3	7.0 0.8	4.2* 0.3	4.8* 0.3
Renal cortical Layer 3	5.6 0.3	6.9 0.8	3.8* 0.4	3.6* 0.3
Renal cortex 4 (juxtamedullary)	4.3 0.3	6.0 0.9	2.7* 0.2	2.8 0.5
Adrenal	2.0 0.1	2.0 0.1	1.2* 0.2	1.3* 0.1
Liver	0.26 0.03	0.51* 0.05	0.27 0.06	0.24 0.07
Pancreas	0.22 0.03	0.21 0.04	0.19 0.03	0.14 0.03
Duodenum	0.54 0.03	0.49 0.04	0.42 0.04	0.56 0.09
Ileum	0.33 0.03	0.34 0.04	0.27 0.03	0.24 0.04
Cecum	0.39 0.05	0.35 0.05	0.32 0.06	0.22 0.04
Triceps	0.034 0.001	0.058* 0.008	0.037 0.004	0.025 0.003
Masseter	0.030 0.001	0.047* 0.005	0.030 0.003	0.021 0.001
Diaphragm	0.035 0.002	0.063* 0.013	0.038 0.008	0.027 0.005
Coronary	0.70 0.06	0.67 0.11	0.59 0.05	0.68 0.10

Values given are means and standard errors of the mean. All control values are the means of 14 observations on seven animals. All others are the means of seven observations on the seven animals.
* $P < 0.02$ compared with control.

33% of control at 90 min, and returned to 73% of control after recovery (table 4).

Blood flows to the duodenum, ileum, colon, and pancreas did not change. There was an initial doubling in hepatic arterial blood flow during hemodilution and hypotension, but this returned to control levels by 90 min. Adrenal blood flow was decreased significantly at 90 min and remained decreased during recovery.

After 30 min, retinal blood flow had decreased to 77% of control, and by 90 min had decreased by 72%. Calculated oxygen delivery to retina decreased to 44% of control at 30 min and to 22% of control at 90 min. Oxygen delivery returned to only 48% of control after recovery (table 4).

Blood flow to skeletal muscle, as represented by masseter and triceps, increased 70% after 30 min but returned to control levels after 90 min and during recovery. Similar changes were seen in blood flow to diaphragm.

Discussion

Deliberate hemodilution to an hematocrit of 20–30% has been used in a number of anesthetic and surgical situations, including total hip replacements, aortoiliac reconstructive surgery, gastric surgery, and open-heart surgery.[1,2,10–13] The decrease in hemoglobin concentration produced in these situations may result in a 50% decrease in the oxygen-carrying capacity of each unit volume of blood. Clearly, under these conditions, maintenance of oxygenation at all levels, from gas exchange in the lungs, to oxygen delivery in the tissues, must be ensured.

We found no evidence that gas exchange in the lungs was impaired during the period of hemodilution and hypotension. At no time during the experiment were there significant changes in the alveoloarterial partial pressure gradient for oxygen (table 1), and so we conclude that over a period of 90 min the combination of hemodilution and hypotension does not pose a threat to gas exchange in normal lungs.

In these experiments, hypotension resulted entirely from a decrease in total peripheral resistance (table 1), rather than from a decrease in cardiac output, and so another critical factor in oxygen delivery, total blood flow, was maintained during the procedure. The lack of development of a metabolic acidosis during the 90 min of hemodilution and hypotension presumably indicates that whole body oxygen delivery was maintained adequately, despite the large decreases in arterial pressure and hemoglobin concentration. One reason for this may be the decrease in total body oxygen consumption associated with the use of trimethaphan.[14]

TABLE 4. Calculated Oxygen Delivery to the Whole Body and Several Tissues Groups Shown as Per Cent of Control

Tissue	Calculated Oxygen Delivery as Per Cent Control		
	30 minutes	90 minutes	Recovery
Whole body (QCa)	58	71	96
Brain	84	71	69
Retina	44	22	48
Outer renal cortex	49	33	73
Ileum	59	48	70
Muscle (triceps)	98	63	70
Heart	55	49	93

Oxygen content was calculated from oxygen partial pressures assuming a normal oxy-hemoglobin dissociation curve for dog blood.[7]

At the next level in the oxygen transport chain to tissues, we were concerned about maintenance of blood flow to specific tissue beds, especially to heart, brain, liver, and kidneys. Further, we were concerned that changes in the distribution of blood flow within specific organs might lead to focal tissue ischemia and hypoxia. Such changes might not be reflected by a change in arterial *p*H or by development of a metabolic acidosis.

The combination of hemodilution and hypotension could compromise myocardial oxygen delivery in a number of ways. Presumably, part of the response to an increased oxygen requirement in the heart will be vasodilation, but after maximal vasodilation, the primary determinant of endocardial flow is the pressure gradient between the aortic diastolic pressure and the intramyocardial forces. The heart could be compromised during hemodilution and hypotension by a decrease in coronary flow, an alteration in the intramyocardial distribution of flow secondary to the 40% reduction in the perfusing pressure gradient, or by a decrease in oxygen transport to the heart secondary to hemodilution. Buckberg and Brazier[15] produced isovolemic hemodilution with 6% dextran-70 in dogs, to lower hemoglobin concentrations to as low as 5 g/dl. This drop in O_2-carrying capacity was well tolerated, due to increases in total myocardial blood flow and maintenance of normal distribution of coronary flow. However, when oxygen requirements of the heart were increased by production of a mild aortic stenosis, the dogs developed electrocardiographic signs of subendocardial ischemia, suggesting that the margin of safety during hemodilution may be rather small, especially in the endocardium. Similarly, Hagl *et al.*[16] demonstrated in dogs that during hemodilution (Hct = 15%) myocardial oxygen demand is not met adequately if coronary reserve capacity was depleted by mild obstruction of the left anterior descending coronary artery.

However, in our study this did not appear to be a problem—coronary blood flow was maintained at control levels throughout the period of hemodilution and hypotension (table 3), while calculated oxygen delivery decreased to 55% of control at 30 min and to 49% of control at 90 min (table 4). The 'pressure–rate' product in these animals actually decreased by about 40%; if we assume this product to be indicative of myocardial oxygen requirements, then it appears myocardial oxygen delivery did not fall out of proportion to myocardial oxygen demand.

In another critical area, brain, blood flow initially was increased about 40–50% over control levels (table 2), an increase that maintained calculated cerebral oxygen delivery at about 84% of prehemodilution levels (table 4), and that therefore would allow maintenance of cerebral oxygen consumption at control levels with relatively minor decreases in cerebral venous oxygen tension. The significance of the selective redistribution of blood flow into the central nuclei and brain-stem is not obvious at this time. By 90 min, calculated oxygen delivery to the brain was decreased to 71% of control (table 4) because of a decrease in cerebral blood flow (table 2). While oxygen consumption still could be maintained by increases in oxygen extraction, this progressive decrease in oxygen delivery to the brain with time is disturbing.

Maintenance of renal blood flow is also of major concern during this procedure. Migdal *et al.*[17] have shown that hemodilution produces a shift of blood flow into the superficial layers of the renal cortex, due possibly to the decrease in renin production that occurs when hematocrit drops[18] or an inhibition of prostaglandin synthesis produced by the hemodilution.[19] On the other hand, hypotension within the autoregulatory pressure range (>70 mmHg), produced by aortic constriction, has been shown to result in redistribution of blood flow from the outer cortical layers to the juxtamedullary layers and further decreases in pressures result in a fall in absolute renal flow.[20] Thus, there are at least two mechanisms that may work to cause a maldistribution of the renal blood flow as well as possibly cause a decrease in flow, either of which might lead to medullary or cortical ischemia with resultant renal damage. We found decreases in renal cortical blood flow in all cortical layers after 90 min. Renal cortical blood flow decreased to about 60% of control by 90 min (table 3) and calculated oxygen delivery (table 4) decreased to 50% of control by 30 min and to 33% of control by 90 min. These changes are disturbing, since they could presage development of renal ischemia. Autoregulation of renal blood flow in the face of both hemodilution and hypotension may not be a phenomenon that the body can maintain.

In summary, our results suggest several possible concerns related to the technique. First, there were decreases in calculated oxygen delivery to the renal cortex to 33% of the control values after 90 min (table 4). Second, retinal blood flow decreased to 33% of control by 90 min, with a fall in calculated oxygen delivery to retina to 22% of control. Third, the increase in cerebral blood flow seen at 30 min was not maintained at 90 min, producing a progressive fall with time in calculated oxygen delivery to the brain. If these changes are all progressive, they may indicate an inability of the body to maintain appropriate autoregulation of blood flow and so may represent a severe threat to the patient.

Further, these studies were done with the animals breathing 100% oxygen, with arterial oxygen pressures of about 500 mmHg, when oxygen carriage in the dissolved form alone (1.5 ml/dl) can provide a significant

fraction of the normal A-V oxygen difference and so provide a margin of safety. Any attempt to decrease FI_{O_2} or any change in the efficiency of gas exchange that might decrease Pa_{O_2} could be extremely dangerous to oxygen delivery.

A major difficulty inherent in interpretation of results obtained from the use of microspheres is that they measure blood flow to the tissue beds, not oxygen delivery or oxygen utilization in those beds. Thus, demonstration that blood flow to a particular bed is decreased does not necessarily indicate that oxygen utilization in that bed also has decreased—oxygen utilization could be maintained by an increase in extraction of oxygen. However, we feel the combination of a decrease in blood flow to a tissue bed, at the same time oxygen extraction is limited by hemodilution, probably will result in impairment of oxygen delivery and utilization in the tissues. Given this assumption, the results reported indicate that, at least for 30 min, hemodilution and hypotension could be a relatively safe technique. However, changes seen by 90 min that could result in major decreases in oxygen delivery to important tissue beds lead us to conclude that use of the technique in humans, if carried to the degree effected in these studies in dogs, might be harmful. This might be a useful technique for short periods for patients who refuse blood transfusion or who are difficult to cross-match.

References

1. Laks K, Pilon RN, Klovekorn WP, Anderson W, MacCallum JR, O'Connor NE: Acute hemodilution: Its effect on hemodynamics and oxygen transport in the anesthetized patient. Ann Surg 180:103–109, 1974
2. Laks K, Pilon RN, Anderson W, MacCallum JR, O'Connor NE: Intraoperative prebleeding in man: Effect of colloid hemodilution on blood volume, lung water, hemodynamics, and oxygen transport. Surgery 78:130–137, 1975
3. Wildsmith JAW, Drummond GB, MacRae WR: Blood-gas changes during induced hypotension with sodium nitroprusside. Br J Anaesth 47:1205–1211, 1975
4. Bennett EJ, Salem MR, Sakul P, Dalal FY, McNeill TW, DeWald RL: Induced hypotension for spinal corrective procedures. Middle East J Anesthesiol 4:177–186, 1974
5. Wong KC, Webster LR, Coleman SS, Dunn, HK: Hemodilution and induced hypotension for insertion of a Harrington rod in a Jehovah's Witness patient. Clin Orthop 152:237–240, 1980
6. Heymann MA, Payne BD, Hoffman JIE, Rudolph AM: Blood flow measurements with radio-nuclide labelled particles. Prog Cardiovasc Dis 20:55–79, 1977
7. Rossing RG, Cain SM: A nomogram relating pO2, pH, temperature, and hemoglobin saturation in the dog. J Appl Physiol 21:195–201, 1966
8. Wallenstein S, Zucker CL, Fleiss JL: Some statistical methods useful in circulation research. Circ Res 47:1–9, 1980
9. Harnett DL: Introduction to Statistical Methods. Reading, Addison-Wesley, 1975, pp 487–500
10. Klovekorn WP, Pichlmaier H, Ott E, Bauer H, Sunder-Plassmann L, Jesch F, Messmer K: Acute preoperative hemodilution in surgical patients. Bibl Haematologica 41:248–259, 1975
11. Laks H, Handin RI, Martin V, Pilon RN: The effects of acute normovolemic hemodilution on coagulation and blood utilization in major surgery. J Surg Res 20:225–230, 1976
12. Orlowski T, Lepert R, Madry KL: Moderate hemodilution technic in surgical procedures. Am J Surg 130:332–337, 1975
13. Taylor KM, Bain WH, Jones JV, Walker MS: The effect of hemodilution on plasma levels of cortisol and free cortisol. J Thorac Cardiovasc Surg 72:57–61, 1976
14. Theye RA, Tuohy GF: Effect of trimethaphan on hemodynamics and oxygen consumption during halothane anesthesia in man. Br J Anaesth 37:144–151, 1965
15. Buckberg G, Brazier J: Coronary blood flow and cardiac function during hemodilution. Bibl Haematologica 41:173–189, 1975
16. Hagl S, Heimisch W, Meisner H, Erben R, Baum M, Mendler N: The effect of hemodilution on regional myocardial function in the presence of coronary stenosis. Basic Res Cardiol 72:344–364, 1977
17. Migdal S, Alexander EA, Bruns FJ, Riley AL, Levinsky NG: Effect of hemodilution on the distribution of renal blood flow. Circ Res 36:71–75, 1975
18. McDonald KM: Effect of hematocrit and colloid-induced changes in blood viscosity on renal hemodynamics and renin release in the dog. Circ Res 34:112–122, 1974
19. Kirshchenbaum MA, White N, Stein JH, Ferris TF: Redistribution of renal cortical blood flow during inhibition of prostaglandin synthesis. Am J Physiol 227:801–805, 1974
20. McNay JL, Abe Y: Pressure-dependent heterogeneity of renal cortical blood flow in dogs. Circ Res 27:571–587, 1970