J Anesth (1996) 10:16–21

Journal of
Anesthesia

Hemodynamics and oxygen consumption during warm heart surgery

TAKASHI IGARASHI[1], DAI SONEHARA[1], KEN IWAHASHI[1], HIROZUMI ASAHARA[1], AKIO KONISHI[2], and KUNIO SUWA[3]

[1]Department of Anesthesia, Mitsui Memorial Hospital, 1 Izumi-cho, Kanda, Chiyoda-ku, Tokyo 101, Japan
[2]Department of Anesthesia, New Tokyo Hospital, 473-1 Nemoto, Matsudo, Chiba 271, Japan
[3]Department of Anesthesiology, Faculty of Medicine, University of Tokyo, 7-3-1 Hongo, Bunkyo-ku, Tokyo 113, Japan

Abstract: We compared the effects of normothermic cardiopulmonary bypass (CPB) with those of hypothermic CPB in patients who underwent coronary artery bypass grafting (CABG) with respect to hemodynamics and oxygen balance. The patients in our study were divided into two groups according to temperature during CPB: systemic normothermia combined with warm blood cardioplegia (group W, $n = 36$) and systemic hypothermia combined with cold crystalloid cardioplegia (group C, $n = 26$). In group W, the use of direct-current (DC) defibrillators was less frequent after release of the cross clamp, and the duration of CPB and of reperfusion was shorter. After CPB, the cardiac index and arterial pressure were higher and the dosages of dopamine were lower in group W than in group C. The serum glucose level during and after CPB was lower and the base excess during CPB was higher in group W than in group C. Oxygen consumption ($\dot{V}o_2$) was unchanged throughout the operation in group W, while it decreased during CPB and increased at the end of surgery in group C. The oxygen extraction ratio (ERo_2) increased during CPB in group W, while it was unchanged throughout the operation in group C. Mixed venous oxygen saturation ($S\bar{v}o_2$) was maintained above 65% during and after CPB in group W and group C. Our results showed that normothermia may be superior to hypothermia during CPB with respect to recovery of cardiac function and avoidance of hyperglycemia. The whole-body oxygen demand-supply balance may be preserved during normothermic as well as hypothermic CPB.

Key words: Coronary artery bypass grafting, Hemodynamics, Oxygen consumption, Warm heart surgery

Introduction

With the advent of warm blood cardioplegia, normothermic cardiopulmonary bypass has been adopted in patients undergoing heart surgery. Warm blood may be used for supplying oxygen to the myocardium, and oxygen consumption of the arrested heart is only 20%–30% of that of the beating heart [1]. Hypothermia adds only a small benefit in further reducing myocardial oxygen consumption [2], while it causes adverse effects such as edema [3], alteration of platelets and leukocytes [4], and reduction of membrane stability [5]. This article describes the effects of normothermic cardiopulmonary bypass combined with warm blood cardioplegia on hemodynamics and whole-body oxygen balance.

Patients and methods

This study was approved by our institutional ethics committee, and informed consent was obtained from all patients. The 62 patients who underwent coronary artery bypass grafting (CABG) were divided into two groups according to core temperature during CPB: systemic normothermia and warm blood cardioplegia (group W, $n = 36$) and systemic hypothermia and cold crystalloid cardioplegia (group C, $n = 26$).

Anesthesia was induced with $4\,\mu g \cdot kg^{-1}$ fentanyl, $0.1\,mg \cdot kg^{-1}$ diazepam, $2\,mg \cdot kg^{-1}$ lidocaine, and $0.1\,mg \cdot kg^{-1}$ pancuronium, and then maintained mainly with isoflurane and an additional $4–5\,\mu g \cdot kg^{-1}$ fentanyl in both groups. Isoflurane was continued throughout the course of anesthesia at a concentration between 0.3% and 1.5%. All patients received $0.5–1\,\mu g \cdot kg^{-1} \cdot min^{-1}$ nitroglycerin and $1–3\,\mu g \cdot kg^{-1} \cdot min^{-1}$ diltiazem intraoperatively. Dopamine was administered to improve low cardiac output or hypotension under adequate preload. When higher doses of dopamine than $5\,\mu g \cdot kg^{-1} \cdot min^{-1}$ were required, epinephrine was administered to improve low cardiac output, and norepinephrine was given to improve persistent hypotension.

During CPB, pump flow was maintained at $2.4\,l \cdot min^{-1}$, and perfusion pressure was kept at between

Address correspondence to: T. Igarashi
Received for publication on June 8, 1995; accepted on October 9, 1995

70mmHg and 100mmHg, by intermittently injecting phenylephrine and nicardipine as a bolus into the extracorporeal circuit. Cardioplegia was accomplished intermittently through the antegrade pathway in both groups by using warm blood in group W and cold crystalloid in group C. The rectal temperature was kept at 35°–37°C in group W and ranged from 28° to 32°C in group C. Systemic rewarming in group C was initiated during the last distal anastomosis, and CPB was terminated at a rectal temperature of over 36.5°C.

Before induction of anesthesia, a catheter was inserted into the left or right radial artery. Immediately after induction, central venous and thermodilution pulmonary artery catheters were inserted via the internal jugular vein. Mean systemic arterial pressure (mAP) and mean pulmonary arterial pressure (mPAP) were assessed by electric integration of the pressure signal. Cardiac output (CO) was measured by thermodilution during the end-expiratory pause, and the mean of three determinations was calculated.

Data were obtained at six points in time: immediately after induction (baseline), before CPB, during CPB, before release of cross clamping, after weaning from CPB, and at the end of surgery. The following specific variables were recorded at each of these points: phasic systemic arterial pressure, mAP, mPAP, mean central venous pressure (mCVP), pulmonary capillary wedge pressure (PCWP), and CO. Cardiac index (CI), systemic vascular resistance (SVR), and pulmonary vascular resistance (PVR) were calculated by standard formulas.

Arterial and mixed venous blood samples were obtained for blood gas analyses, hemoglobin (Hb), and serum glucose. Blood gases were analyzed at 37°C. During CPB, blood samples from the drainage site of the extracorporeal circuit were substituted for mixed venous blood samples. Oxygen content, delivery, uptake, and extraction ratio were calculated by the following standard formulas:

$$O_2 \text{ content} = (Hb \times 1.34 \times \%O_2 \text{ saturation})/100 + (Po_2 \times 0.003)$$

$$\dot{D}o_2 = O_2 \text{ delivery} = Cao_2 \times (\text{blood flow})$$

$$\dot{V}o_2 = O_2 \text{ consumption} = (Cao_2 \times Cvo_2) \times (\text{blood flow})$$

$$ERo_2 = O_2 \text{ extraction ratio} = (Cao_2 \times Cvo_2)/Cao_2$$

where Hb is hemoglobin, Cao_2 is arterial oxygen content, Cvo_2 is venous oxygen content, blood flow represents total body flow (CI or pump flow rate), and Po_2 is oxygen partial pressure.

The repeated trials of DC defibrillation after release of the aortic cross clamp, the duration of reperfusion, the use and amount of catecholamines and intraaortic balloon pumping (IABP) after weaning from CPB, and the maximal postoperative level of serum creatine kinase isozyme MB (CK-MB) were recorded.

Continuous variables were expressed as mean ± SD, and were analyzed by using repeated-measure analysis of variance (ANOVA) following Dunn's procedure for time-course data, and by using Student's *t*-test for data between groups C and W. The incidence of epinephrine administration was analyzed by the chi-squared and Fisher's exact probability tests. A P value <0.05 was considered significant.

Results

Demographic data (Table 1)

There were no differences between the groups with respect to age, preoperative ejection fraction of the left ventricle, intraoperative body fluid balances, and the number of grafted vessels. The durations of surgery, aortic cross clamping, CPB, and reperfusion were all shorter in group W. There were fewer repeated trials of DC defibrillation after release of the cross clamp, and the dosages of dopamine after CPB were lower in group W. No significant differences were found in postoperative CK-MB levels. Phenylephrine and nicardipine dosages during CPB totaled 4.6 ± 2.2mg and 1.4 ± 0.7mg, respectively, in group C, and 14.0 ± 3.9mg and 0mg, respectively, in group W. Epinephrine was administered after CPB at a dosage of $0.2\,\mu g \cdot kg^{-1} \cdot min^{-1}$ for a patient in group C, and $0.1\,\mu g \cdot kg^{-1} \cdot min^{-1}$ for another patient in group W. No patients resulted in requiring norepinephrine or IABP, and none showed any neurological deficits or any new Q waves on electrocardiogram perioperatively.

Hemodynamics (Table 2)

After induction of anesthesia, cardiac function was similar in the two groups. During CPB and before release of the aortic cross clamp, SVR was higher than the baseline values in both groups, and was lower in group W than in group C.

After CPB, the CI was higher, SVR was lower, and mAP was similar as compared with baseline values in both groups. CI and mAP after CPB were higher and SVR and was lower in group W than in group C. At the end of surgery, mAP was higher in group W than in group C.

Blood laboratory data (Table 3)

After induction of anesthesia, there were no differences between the two groups with respect to Hb, Sao_2, $S\bar{v}o_2$, base excess (BE), $Paco_2$, venous-arterial CO_2 gradient ($v\text{-}aPco_2$), and serum glucose. Hb decreased to $6.1\,g \cdot dl^{-1}$ during CPB, and returned to the baseline level there-

Table 1. Demographic data

	Group C	Group W
Preoperative		
Age (years)	63 ± 14	61 ± 11
EF (%)	56 ± 15	59 ± 14
Intraoperative		
OPE time (min)	297 ± 54	238 ± 63*
AXC time (min)	65 ± 24	39 ± 17*
CPB time (min)	119 ± 37	65 ± 29*
Reperfusion (min)	55 ± 13	18 ± 10*
No. vessels grafted	2.9 ± 0.8	3.1 ± 0.9
Fluid balance (ml)	+4613 ± 1778	+4386 ± 1478
Weaning from CPB		
DC (no. times)	0.4 ± 0.5	0*
Dopamine ($\mu g \cdot kg^{-1} \cdot min^{-1}$)	2.9 ± 1.5	1.6 ± 1.5*
Epinephrine	1/26 (3.8%)	1/36 (2.8%)
Postoperative		
Max. CK-MB ($IU \cdot ml^{-1}$)	43 ± 16	41 ± 19

EF, ejection fraction of left ventricle; OPE, operation; AXC, aortic cross clamp; CPB, cardiopulmonary bypass; DC, direct-current defibrillation; CK-MB, serum creatine kinase isozyme MB.
* $P < 0.05$ *vs* group C.

Table 2. Hemodynamics in groups C and W

	After induction	Before CPB	During CPB	Release of AXC	After CPB	End of surgery
mAP (mmHg)						
C	82 ± 6	82 ± 11	83 ± 15	92 ± 13†	81 ± 7	83 ± 9
W	81 ± 8	83 ± 7	77 ± 10*	85 ± 15*	84 ± 7*	88 ± 7*†
mPAP (mmHg)						
C	18 ± 5	16 ± 4	—	—	15 ± 4	15 ± 4
W	17 ± 4	15 ± 5	—	—	14 ± 4	14 ± 4
PCWP (mmHg)						
C	13 ± 6	11 ± 5	—	—	10 ± 4	10 ± 5
W	12 ± 4	10 ± 4	—	—	10 ± 4	10 ± 4
CVP (mmHg)						
C	9 ± 2	6 ± 3	0	0	6 ± 2	8 ± 2
W	8 ± 2	6 ± 2	0	0	5 ± 2	7 ± 2
HR ($beats \cdot min^{-1}$)						
C	69 ± 10	76 ± 8†	—	—	86 ± 4†	86 ± 4†
W	70 ± 7	74 ± 5†	—	—	84 ± 7†	85 ± 5†
CI ($l \cdot min^{-1} \cdot m^{-2}$)						
C	2.3 ± 0.5	2.9 ± 0.6†	2.4 ± 0	2.4 ± 0	3.3 ± 0.6†	3.6 ± 0.5†
W	2.4 ± 0.5	3.0 ± 0.6†	2.4 ± 0	2.4 ± 0	3.6 ± 0.5*†	3.6 ± 0.6†
SVR ($dynes \cdot s \cdot cm^{-5}$)						
C	1658 ± 482	1405 ± 326	1824 ± 436†	2032 ± 394†	1236 ± 343†	1156 ± 367†
W	1491 ± 357	1319 ± 322†	1652 ± 293*†	1714 ± 326*†	1072 ± 200*†	1161 ± 271†
PVR ($dynes \cdot s \cdot cm^{-5}$)						
C	102 ± 52	79 ± 39	—	—	85 ± 39	86 ± 35
W	93 ± 33	82 ± 31	—	—	59 ± 23	61 ± 17

CPB, cardiopulmonary bypass; AXC, aortic cross clamp; mAP, mean arterial pressure; mPAP, mean pulmonary artery pressure; PCWP, pulmonary capillary wedge pressure; CVP, central venous pressure; HR, heart rate; CI, cardiac index; SVR, systemic vascular resistance; PVR, pulmonary vascular resistance.
* $P < 0.05$ vs group C; † $P < 0.05$ *vs* baseline (after induction).

after. Svo_2 in group C increased to 89% during CPB, and decreased to 69% before release of the aortic cross clamp. $S\bar{v}o_2$ in group W deceased to 69% during CPB, and to 66% at release of the aortic cross clamp. $S\bar{v}o_2$ in both groups returned to baseline values after CPB, and decreased again at the end of surgery. BE was higher and serum glucose was lower in group W than in group C during and after CPB. Sao_2, $Paco_2$, and $v\text{-}aPco_2$ were unchanged regardless of time points in both groups.

Oxygen balance (Table 4)

Before and after CPB, there were no differences between the two groups with respect to $\dot{D}o_2$, $\dot{V}o_2$, and ERo_2. $\dot{D}o_2$ decreased during CPB and increased at the

end of surgery in both groups. $\dot{V}o_2$ was unchanged throughout the operation in group W, while it decreased during CPB and increased at the end of surgery in group C. ERo_2 increased during CPB in group W, while it was unchanged throughout the operation in group C. $\dot{V}o_2$ and ERo_2 during CPB were higher in group W than in group C.

Discussion

Systemic normothermia combined with warm blood ardioplegia was found to be an excellent technique for cardiac surgery. The following reasons may be given.

First, the patients required fewer attempts of DC defibrillation after release of the cross clamp, and were weaned from CPB with lower dosages of catecholamine. Similar effects of warm cardioplegia were documented, in that hearts resumed their normal sinus rhythm spontaneously [6], postoperative ventricular functions were better, and there was less of a requirement for circulatory support [7,8]. Aerobic warm blood has biochemical and mechanical advantages over cold crystalloid with regard to oxygen delivery to the myocardium during aortic cross clamp. In our study, the

Table 3. Rectal temperature and laboratory data from blood specimens taken from groups C and W

	After induction	Before CPB	During CPB	Release of AXC	After CPB	End of surgery
RT (°C)						
C	36.0 ± 0.6	34.6 ± 0.9	30.1 ± 3.0†	32.7 ± 2.5†	36.8 ± 0.9	36.4 ± 0.2
W	36.0 ± 0.6	34.7 ± 0.7	35.0 ± 0.5*	36.0 ± 0.8*	37.1 ± 0.3	36.5 ± 0.6
Hb ($g \cdot dl^{-1}$)						
C	10.3 ± 1.8	9.6 ± 1.5	6.1 ± 1.1†	7.0 ± 1.2†	7.2 ± 0.8†	8.8 ± 1.0†
W	10.9 ± 1.8	9.4 ± 0.9	6.1 ± 1.0†	6.8 ± 1.0†	7.1 ± 0.9†	8.8 ± 0.9†
Sao_2 (%)						
C	99.3 ± 0.6	99.2 ± 0.4	99.7 ± 0.1	99.3 ± 0.9	99.8 ± 0.2	99.0 ± 0.8
W	99.4 ± 0.5	99.3 ± 0.4	99.7 ± 0.2	99.5 ± 0.3	99.7 ± 0.4	99.2 ± 0.4
$S\bar{v}o_2$ (%)						
C	74.9 ± 9.2	79.1 ± 6.7	81.2 ± 9.3†	69.2 ± 10.1	72.5 ± 8.7	66.8 ± 10.8
W	76.9 ± 9.1	78.1 ± 8.3	69.1 ± 10.1*†	66.1 ± 8.1†	72.4 ± 9.6	68.6 ± 9.2
BE ($mmol \cdot l^{-1}$)						
C	+1.5 ± 2.0	+1.2 ± 1.5	+0.9 ± 1.5	−0.2 ± 1.9	+0.1 ± 2.7	+1.0 ± 3.6
W	+1.3 ± 1.4	+1.2 ± 1.5	+2.0 ± 1.5*	+1.0 ± 2.1*	+1.5 ± 2.2*	+2.1 ± 2.4
$Paco_2$ (mmHg)						
C	36 ± 3	34 ± 5	37 ± 4	33 ± 7	34 ± 4	37 ± 5
W	35 ± 4	33 ± 3	35 ± 4	35 ± 5	33 ± 4	34 ± 5*
v-aCO_2 (mmHg)						
C	4.7 ± 3.9	4.4 ± 3.5	3.8 ± 2.1	5.2 ± 2.3	3.8 ± 1.6	4.0 ± 2.0
W	4.9 ± 3.4	3.5 ± 2.7	3.3 ± 2.0	5.6 ± 2.3	4.4 ± 1.7	4.8 ± 2.7
glucose ($mg \cdot dl^{-1}$)						
C	119 ± 43	164 ± 42†	301 ± 75†	339 ± 79†	308 ± 68†	278 ± 79†
W	113 ± 37	143 ± 38†	204 ± 58*†	204 ± 72*†	214 ± 68*†	219 ± 67*†

CPB, cardiopulmonary bypass; AXC, aortic cross clamp; RT, rectal temperature; Hb, hemoglobin; Sao_2, arterial hemoglobin saturation; $S\bar{v}o_2$, mixed venous hemoglobin saturation; BE, base excess; $Paco_2$, arterial Pco_2; v-aCO_2, venous-arterial Pco_2 gradient.
* $P < 0.05$ *vs* group C; † $P < 0.05$ *vs* baseline (after induction).

Table 4. Oxygen balance in groups C and W

	After induction	Before CPB	During CPB	Release of AXC	After CPB	End of surgery
$\dot{D}o_2$ ($ml \cdot min^{-1} \cdot m^{-2}$)						
C	356 ± 80	385 ± 73	223 ± 38†	245 ± 38†	365 ± 57	443 ± 80†
W	375 ± 107	394 ± 84	217 ± 30†	242 ± 30†	389 ± 69	446 ± 84†
$\dot{V}o_2$ ($ml \cdot min^{-1} \cdot m^{-2}$)						
C	92 ± 20	83 ± 18	54 ± 15†	81 ± 22	113 ± 24	155 ± 51†
W	94 ± 54	80 ± 14	76 ± 10*	82 ± 27	106 ± 27	129 ± 26
ERo_2						
C	0.27 ± 0.08	0.22 ± 0.06	0.25 ± 0.08	0.34 ± 0.10	0.32 ± 0.06	0.36 ± 0.10
W	0.25 ± 0.07	0.23 ± 0.06	0.36 ± 0.08*†	0.35 ± 0.08	0.33 ± 0.08	0.29 ± 0.06

CPB, cardiopulmonary bypass; AXC, aortic cross clamp; $\dot{D}o_2$, oxygen delivery; $\dot{V}o_2$, oxygen consumption; ERo_2 extraction ratio of oxygen.
* $P < 0.05$ *vs* group C; † $P < 0.05$ *vs* baseline (after induction).

maximum postoperative CK-MB level was similar between groups W and C, but there was less total CK-MB release reported in warm cardioplegia than in cold cardioplegia [7].

Second, systemic normothermia required a shorter CPB, by requiring no time for cooling and rewarming. This effect may in turn have also resulted in higher CI and mean systemic arterial pressure after normothermic CPB. A CPB time of longer than 150 min is one of the factors responsible for postoperative ventricular dysfunction [9].

Third, SVR was lower during normothermic CPB than during hypothermic CPB. Systemic vasodilatation during normothermia has a clear advantage over vasoconstriction during hypothermia, with respect not only to peripheral perfusion but also to arterial graft flow. Arterial grafts may respond to temperature similarly to regular peripheral arteries. Ease in weaning patients from CPB may be attributed to the effects of both warm blood cardioplegia and afterload reduction as a result of peripheral vasodilatation during normothermic CPB.

In regard to oxygen balance, the entire body achieved better aerobic metabolism during and after normothermic CPB were adequate oxygen balance was shown by a $S\bar{v}o_2$ of higher than 60%, an ERo_2 lower than 0.4, and a v-aCO_2 gradient smaller than 6 mmHg in our study. Lactic acidosis does not usually occur unless $S\bar{v}o_2$ falls below 50% in normothermia [10]. The distribution of blood flow does not change during normothermic CPB, where increases in oxygen extraction were shown in the brain, kidney, small bowel, and muscle [11]. Thus, care should be taken to ensure oxygen delivery to the brain, although we found no patients who showed postoperative neurological deficits in our study. A decrease in pump flow, extreme hemodilution, an increase in pH, and a decrease in Pco_2 should be avoided during normothermic CPB.

In contrast, hypothermia diminishes whole-body oxygen consumption. In case of CPB accidents, this decrease in oxygen consumption allows more time to correct the problem. However, the transport of oxygen to certain tissues can be limited by arteriovenous shunting during hypothermic CPB. Mixed venous blood represents the mean of venous effluents from a wide variety of tissues with different metabolic rates, oxygen extraction, and tissue capillary densities [12]. Normal $S\bar{v}o_2$ can be maintained even in the face of inadequate tissue oxygenation in areas with low O_2 extraction ratios receiving a high blood flow. Blood flow to the carotid, renal, and superior mesenteric arteries decreases during hypothermic CPB, whereas blood flow to the femoral artery increases [11]. The alteration of blood flow distribution causes anaerobic metabolism in some organs. We found increases in $\dot{V}o_2$ and ERo_2 at the end of hypothermic surgery. This suggests that certain tissues might have failed in extracting oxygen during hypothermic CPB, and that the oxygen supply to certain tissues may be quite different at the end of surgery.

We found that hyperglycemia diminished and the degree of metabolic alkalosis was greater during and after CPB under normothermia, as compared with hypothermia. This shows that normothermic CPB minimized the effects of hypothermia on the stimulation of sympathetic nerves [13], the release of intrinsic catecholamines [14], and alteration of the blood flow during CPB [11]. Thus, normothermic CPB may be less stressful physiologically than hypothermic CPB.

For this reason, systemic normothermia combined with warm blood cardioplegia may be an excellent alternative not only for myocardial protection but also for total-body protection during CPB. Warm heart surgery may be appropriate for patients in critical condition with impaired preoperative cardiac function.

References

1. Buckberg GD, Brazier JR, Nelson RL, Goldstein SM, McConnell DH, Cooper N (1977) Studies of the effects of hypothermia on regional myocardial blood flow and metabolism during cardiopulmonary bypass: 1. The adequately perfused beating, fibrillating and arrested heart. J Thorac Cardiovasc Surg 73:87–94
2. Buckberg GD (1991) Myocardial temperature management during aortic cross clamping for cardiac surgery. J Thorac Cardiovasc Surg 102:895–903
3. Kaijser L, Jansson E, Schmidt W, Bomfim V (1985) Myocardial energy depletion during profound hypothermic cardioplegia for cardiac operations. J Thorac Cardiovasc Surg 90:896–900
4. Teoh KH, Christakis GT, Weisel RD (1987) Dipyridamole reduces myocardial platelet and leukocyte deposition following ischemia and cardioplegia. J Surg Res 42:642–652
5. McMurchie EJ, Raison JK, Cairncross KD (1973) Temperature-induced phase changes in membranes of heart: a contrast between the thermal response of poikilotherms and homeotherms. Comp Biochem Physiol 44:1017–1026
6. Lichtenstein SV, Ashe KA, Dalati HEL, Cusimano RJ, Panos A, Slutsky AS (1991) Warm heart surgery. J Thorac Cardiovasc Surg 101:269–274
7. Yau TM, Ikonomidis JS, Weisel RD, Mickle DAG, Ivanov J, Mohabeer MK, Tumiati L, Carson S, Liu P (1993) Ventricular function after normothermic versus hypothermic cardioplegia. J Thorac Cardiovasc Surg 105:833–844
8. Allen BS, Rosenkranz ER, Buckberg GD, Davtyan H, Laks H, Tillisch J, Drinkwater DC (1989) Studies on prolonged acute regional ischemia: 6. Myocardial infarction with left ventricular power failure: a medical/surgical emergency requiring urgent revascularization with maximal protection of remote muscle. J Thorac Cardiovasc Surg 98:691–703
9. Royster RL, Butterworth JF, Prough DS, Johnston WE, Thomas JL, Hogan PE, Case LD, Gravlee GP (1991) Preoperative and intraoperative predictors of inotropic support and long-term outcome in patients having coronary artery bypass grafting. Anesth Analg 72:729–736
10. Kandel G, Aberman A (1983) Mixed venous oxygen saturation: Its role in the assessment of the clinically ill patient. Arch Int Med 143:1400–1402

11. Lazenby WD, Ko W, Zeano JA, Lebowitz N, Shin YT, Isom OW, Krieger KH (1992) Effects of temperature and flow rate on regional blood flow and metabolism during cardiopulmonary bypass. Ann Thorac Surg 53:957–964
12. Rudy LW, Boucher JK, Edmunsa LH (1972) The effect of deep hypothermia and circulatory arrest on the distribution of systemic blood flow in rhesus monkeys. J Thorac Cardiovasc Surg 64:706–713
13. Hine IP, Wood WG, Mainwaring-Burton RW, Butler MJ, Irving MH, Booker B (1976) The adrenergic response to surgery involving cardiopulmonary bypass, as measured by plasma and urinary catecholamine concentrations. Br J Anaesth 48:355–363
14. Tan CK, Glisson SN, El Etr AA, Ramakrishnaiah KB (1976) Levels of circulating norepinephrine and epinephrine before, during and after cardiopulmonary bypass in man. J Thorac Cardiovasc Surg 71:928–931