J Anesth (1998) 12:125–129

Journal of
Anesthesia

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Open-heart surgery without homologous blood transfusion in infants and children under simple deep hypothermia

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Abstract

Purpose. To investigate the hematological changes during the perioperative period of open-heart surgery without homologous blood transfusion under simple deep hypothermia in infants and small children, and to define the limits of body weight for open-heart surgery without homologous blood transfusion under simple deep hypothermia.

Methods. We performed open-heart surgery without homologous blood transfusion under simple deep hypothermia on eight children, four infants, and a neonate with diagnoses of atrial septal defect, ventricular septal defect, on total anomalous pulmonary venous return (TATVR). All patients except for one with TAPVR were surface-cooled with ice water under deep ether anesthesia. Hematological examinations were performed seven times during the perioperative period.

Results. The body weight of the patients ranged from 2.5 to 15.0 kg (mean ± SD, 9.5 ± 3.5 kg) and the blood loss from 0.7 to 7.1 g·kg^{-1} (4.6 ± 2.0 g·kg^{-1}) The lowest values of the hematological findings in each case after surgery were as follows: Hb ranged from 7.6 to 10.9 g·dl^{-1} (8.8 ± 1.0 g·dl^{-1}), blood platelet count from 158 × 10^3 to 337 × 10^3 cells·μℓ$^{-1}$ (271 ± 88 × 10^3 cells·μℓ$^{-1}$), and total protein from 4.3 to 5.5 g·dl^{-1} (5.0 ± 0.4 g·dl^{-1}).

Conclusion. Severe anemia and hypoproteinemia were not detected in any case, and, in particular, the reduction of the platelet count was slight. No events occurred as a result of decreased Hb concentration, serum protein, or both.

Key words: Open-heart surgery, Simple deep hypothermia, Blood transfusion, Children

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Received for publication on September 22, 1997; accepted on March 27, 1998

Introduction

It has been a serious concern that blood transfusion may cause complications such as serum hepatitis, acquired immune deficiency syndrome (AIDS), and graft-versus-host disease (GVHD) after surgery, and open-heart surgery without homologous blood transfusion is becoming an important topic for this reason. Open-heart surgery without homologous blood transfusion is a generally accepted method for adults but not for small children and infants. It should be more positively considered for infants and small children, since they have a longer expectation of life than adults.

We have attempted to perform open-heart surgery without blood transfusion in eight small children, four infants, and a neonate diagnosed with atrial septal defect (ASD), ventricular septal defect (VSD), or total anomalous pulmonary venous return (TATVR) using simple deep hypothermia under deep ether anesthesia except for one with TAPVR. Hematological examinations were performed seven times during the perioperative period. We report the anesthetic procedure and the hematological findings during the perioperative period.

Patients and methods

We studied 13 patients (6 boys and 7 girls) with congenital heart diseases (ASD 5, VSD 7, TAPVR 1) undergoing open-heart surgery under simple deep hypothermia between January 1994 and April 1996. Their body weight ranged from 2.5 to 15.0 kg (mean ± SD, 9.5 ± 3.5) and age from 11 days to 5 years. The characteristics of the patients are shown in Table 1.

The patients were premedicated as follows: atropine sulfate 0.005 mg·kg^{-1}, hydroxyzine hydrochloride 0.5 mg·kg^{-1}, pethidine 0.5 mg·kg^{-1}, and triflupromazine 0.15 mg·kg^{-1} were injected intramuscularly 60 and

Table 1. Patients and resutls

Case no.	Age	Body weight (kg)	Diagnosis	Temperature at cardiac arrest (°C)		Duration of cardiac arrest (min)	Blood loss ($g \cdot kg^{-1}$)	LMWD[a] ($ml \cdot kg^{-1}$)
				Esophageal	Rectal			
1	1y	9.1	VSD	21.9	18.0	23	5.8	18.7
2	5y	15.0	ASD	22.1	20.4	29	6.1	10.0
3	4y	12.5	ASD	21.5	20.0	27	5.9	12.0
4	1y	9.5	VSD	21.3	19.8	23	2.7	12.3
5	4y	10.5	ASD	21.8	19.6	32	3.6	14.3
6	1y	8.0	VSD + PH	20.5	19.8	55	6.8	12.5
7	3y	14.0	ASD	21.0	19.9	21	7.1	14.3
8	5m	6.9	ASD + PH	22.1	17.4	19	5.7	12.3
9	9m	13.0	VSD + PH	19.9	17.5	65	3.5	13.1
10	1y	10.7	VSD	20.8	19.4	34	0.7	13.6
11	8m	5.2	VSD + PH	21.7	16.9	56	2.3	14.4
12[b]	11d	2.5	TAPVR	21.8	16.9	38	2.4	20.8
13	9m	7.1	VSD + PH	20.5	16.4	64	7.0	10.6
Mean		9.5± 3.5		21.3 ± 0.7	18.6 ± 1.4	37 ± 16	4.6 ± 2.0	13.1 ± 2.9

[a] Amount of low-molecular-weight dextran infused during anesthesia.
[b] Plasma protein fraction administered after surgery.
VSD, Ventricular septal defect; ASD, atrial septal defect; PH, pulmonary hypertension; TAPVR, total anomalous pulmonary venous return.

30 min before induction of anesthesia. Anesthesia was induced with thiopental 2.5 $mg \cdot kg^{-1}$ IV, endotracheal intubation was performed with succinylcholine chloride 1 $mg \cdot kg^{-1}$ IV or vecuronium bromide 0.15 $mg \cdot kg^{-1}$, and ventilation was controlled with α-stat regulation in F_1O_2 1.0 during anesthesia. After inhalation of about 1 $ml \cdot kg^{-1}$ ether from a wick-type vaporizer in a closed circuit, the patient was covered with a vinyl sheet and immersed in ice water. The patient inhaled a total of 2.5 ~ 3.0 $ml \cdot kg^{-1}$ ether and was cooled to 20°C esophageal temperature. At 30°C esophageal temperature, 100 units $\cdot kg^{-1}$ of heparin were administered IV. During the period of cooling, 10 $ml \cdot kg^{-1}$ of 10% low-molecular-weight dextran in 5% dextrose (LMWD), lactated Ringer's solution, and prostaglandin E_1 (PGE_1) 0.1 ~ 0.3 $\mu g \cdot kg^{-1} min^{-1}$ were continuously infused. When the target esophageal temperature had been achieved, the ice water was removed and surgery was started.

After clamping the venae cavae, pulmonary artery, and aorta had been clamped, 10 ml of Young's solution (5 g potassium citrate, 12.3 g magnesium sulfate, and 5 mg neostigmine bromide in 500 ml solution) at room temperature was injected transaortically into the coronary artery to induce cardiac standstill, and intracardiac correction was then performed.

Intracardiac blood was sucked into a device (Solcotrans, Solco Basle, Rockland, MA, USA) for the collection and reinfusion of autologous blood and was immediately transfused. After intracardiac correction had been completal, artificial ventilation was started, the clamps were removed from the large vessels, except for the aorta, and 10 ml of cardiotonic cocktail (10 ml of 20% dextrose, 10 ml of 2% $CaCl_2$, and 1 ml of 0.1% norepinephrine in 21 ml solution) with autologous blood sucked from the aorta was pumped transaortically several times into the coronary artery with a syringe. At the moment of achieving cardiac resuscitation, the aortic clamp was removed and the patient wrapped in the vinyl sheet was surface-rewarmed with hot water at 42°C to 36°C esophageal temperature, without getting wet. After cardiac resuscitation, the acid-base balance was corrected with a sodium bicarbonate solution.

During rewarming, lactated Ringer's solution, LMWD 5 $ml \cdot kg^{-1} \cdot h^{-1}$, and dobutamine hydrochloride (DOB) 5 ~ 15 $\mu g \cdot kg^{-1} \cdot min^{-1}$ were infused in order to maintain the optimal arterial blood pressure (ABP) for each body temperature. Protamine sulfate 1 $mg \cdot kg^{-1}$ and furosemide 0.5 $mg \cdot kg^{-1}$ were administered to reverse the effect of the heparin and to cause urination at 30°C esophageal temperature.

During anesthesia, all patients were monitored by electrocardiogram and electroencephalogram, and ABP, central venous pressure (CVP), arterial gas analysis, body temperature in esophagus and rectum, and urine volume were also monitored. Seven blood samples were drawn for hematological examination the day before surgery, the day after surgery, the next 3 days, one week after surgery, and the day of discharge from the hospital (about 2 weeks after surgery). All values of blood samples are given as mean ± standard deviation. Statistical analysis among groups was per-

Table 2. Hematological findings during perioperative period

Finding	Day before surgery	Day after surgery	2nd day	3rd day	4th day	After 1 wk	Day of discharge
WBC	9.8 ± 4.1 (5.3 ~ 17.9)	16.3 ± 6.3* (9.2 ~ 28.5)	15.4 ± 3.1 (11.3 ~ 19.8)	16.3 ± 5.3* (10.6 ~ 27.2)	12.8 ± 3.8 (5.5 ~ 19.3)	8.4 ± 1.4 (6.3 ~ 11.4)	8.5 ± 3.9 (3.2 ~ 17.9)
RBC	4.61 ± 0.39 (4.12 ~ 5.72)	3.82 ± 0.32* (3.15 ~ 4.30)	3.44 ± 0.18* (3.18 ~ 3.76)	3.10 ± 0.28* (2.77 ~ 3.53)	3.15 ± 0.27* (2.77 ~ 3.53)	3.56 ± 0.32* (3.09 ~ 4.05)	3.91 ± 0.30* (3.47 ~ 4.47)
Ht	39.0 ± 7.2 (35.4 ~ 62.9)	32.3 ± 2.8* (28.8 ~ 39.7)	29.3 ± 2.3* (26.1 ~ 35.1)	26.6 ± 2.9* (22.2 ~ 32.9)	26.5 ± 1.9* (22.5 ~ 29.4)	31.3 ± 3.0* (25.8 ~ 36.6)	33.0 ± 2.7* (29.3 ~ 37.5)
Hb	12.9 ± 2.1 (10.5 ~ 19.8)	10.7 ± 1.1* (9.0 ~ 13.3)	9.7 ± 0.7* (8.8 ~ 11.7)	8.8 ± 1.0* (7.9 ~ 11.5)	8.7 ± 0.5* (7.6 ~ 9.2)	10.0 ± 0.8* (8.3 ~ 11.4)	10.6 ± 0.9* (9.6 ~ 12.0)
Pl	386 ± 80 (267 ~ 552)	358 ± 98 (230 ~ 525)	301 ± 68 (208 ~ 429)	265 ± 78 (177 ~ 428)	271 ± 88 (158 ~ 379)	424 ± 151 (245 ~ 732)	534 ± 150* (284 ~ 848)
TP	6.9 ± 0.5 (5.8 ~ 7.6)	5.0 ± 0.4* (4.3 ~ 5.6)	5.3 ± 0.4* (4.6 ~ 5.9)	5.4 ± 0.5* (4.8 ~ 6.2)	5.4 ± 0.4* (4.9 ~ 6.0)	6.3 ± 0.5 (5.5 ~ 6.9)	6.9 ± 0.5 (6.2 ~ 7.9)

WBC, White blood cell count ($\times 10^3 \cdot \mu l^{-1}$); RBC, red blood cell count ($\times 10^6 \cdot \mu l^{-1}$); Ht, hematocrit (%); Hb, hemoglobin concentration ($g \cdot dl^{-1}$); Pl, blood platelet count ($\times 10^3 \cdot \mu l^{-1}$); TP, total protein ($g \cdot dl^{-1}$).
Data from case 12 were rejected.
* $P < 0.05$ vs day before surgery.
Range of data in parentheses.

formed by analysis of variance. The post hoc test was used for comparison with the day before surgery. A P value less than 0.05 was considered significant.

Results

Table 1 shows esophageal temperature, rectal temperature at the beginning of induced cardiac arrest, duration of cardiac arrest, and dose of LMWD during surgery.

We were able to perform cardiac resuscitation easily in all cases by pumping cardiotonics, without cardiac massage or cardioversion. After surgery, mild disorder of the central nervous system was found in case 11.

The blood loss ranged from 0.7 to 7.1 $g \cdot kg^{-1}$ (mean ± SD, 4.6 ± 2.0 $g \cdot kg^{-1}$). The results of perioperative hematological examinations are shown in Table 2. Since plasma protein fraction (PPF) was administered in case 12, this case was excluded from the statistical analysis of total protein (TP).

After surgery, red blood cell count (RBC), hematocrit (Ht), and hemoglobin concentration (Hb) were significantly reduced and did not recover to preoperative values on the day of discharge from the hospital. On the other hand, no significant reduction in blood platelet count was seen, and it was increased over the preoperative value on the day of discharge from the hospital. TP was also reduced significantly but recovered to preoperative values after a week of surgery or on the day of discharge from the hospital.

Table 3 shows the lowest values of the hematological findings from the preoperative day to discharge from the hospital for about 2 weeks of follow-up. Hb ranged from 7.6 to 10.9 $g \cdot dl^{-1}$ (8.8 ± 1.0 $g \cdot dl^{-1}$), blood platelet count from 158 × 10^3 to 337 × 10^3 cells $\cdot \mu l^{-1}$ (271 ± 88 × 10^3 cells $\cdot \mu l^{-1}$), and TP from 4.3 to 5.5 $g \cdot dl^{-1}$ (5.0 ± 0.4 $g \cdot dl^{-1}$).

Table 3. Lowest value of hematological findings after surgery

RBC ($\times 10^6 \cdot \mu\ell^{-1}$)	3.10 ± 0.28 (2.73 ~ 3.95)
Ht (%)	26.5 ± 1.9 (22.2 ~ 32.9)
Hb ($g \cdot dl^{-1}$)	8.8 ± 1.0 (7.6 ~ 10.9)
Pl ($\times 10^3 \cdot \mu\ell^{-1}$)	271 ± 88 (158 ~ 337)
TP ($g \cdot dl^{-1}$)	5.0 ± 0.4 (4.3 ~ 5.5)

Discussion

Today, the targets for open-heart surgery without homologous blood transfusion are mainly adult Jehovah's Witnesses or their children, and it is not yet generally used for infants or small children. In this study, we evaluated the hematological findings after open-heart surgery under deep hypothermia without homologous blood transfusion in infants and small children, and assessed the possibility of performing such surgery without homologous blood transfusion.

It is understood that the indications for open-heart surgery without homologous blood transfusion using cardiopulmonary bypass (CPB) for children should be determined by body weight, and the critical body weight

is considered to be 4 kg [1] or 5.0 kg [2]. However, in this study body weight ranged from 2.5 to 15.0 kg (9.5 ± 3.5 kg).

When such surgery is performed with CPB on a patient weighing 6 kg, even though the artificial lung apparatus and circuit have been reduced in size and the pumps reduced in number as far as possible, the Hb falls to 5.0 g·dl^{-1} during surgery [3]. It is safer to combine CPB with cooling when the hemodilution is high, but the increase in oxygen demand may put demand and supply out of balance during rewarming [4]. The heart is an organ with a low tolerance for hemodilution. Although Ht or Hb is reduced to 20% [5,6] or 4.0 g·dl^{-1} [7] by hemodilution during surgery in small chidren or infants using CPB, the postoperative anemia is less than when simple deep hypothermia is used, because blood can be concentrated to a Hb concentration of about 8 g·dl^{-1} by a hemoconcentrator on weaning from CPB, and blood from the operative wound can be reinfused.

Open-heart surgery using simple deep hypothermia should not in principle cause either bleeding or hemodilution during induced circulatory arrest. Furthermore, the intracardiac blood removed is returned to the patient, and most of the blood loss in our study was considered to have occurred after the surgery.

The reduction in blood platelet count after surgery was very small in this study. In our other study of open-heart surgery without homologous blood transfusion using CPB in infants and small children weighing 16 to 57 kg, the blood platelet count was reduced to (177 ± 32) × 10^3·μl^{-1}. It is suggested that the risk of postoperative bleeding is lower in simple deep hypothermia than in CPB.

Only one case (case 12, 7-day-old baby, body weight 2.5 kg) in this study, a neonate, required treatment with PPF. The total blood loss was 7 g (2.4 g·kg^{-1}). Surgery without homologous blood transfusion succeeded, but PPF was administered for hypoproteinemia 3.8 g·dl^{-1} on the day after surgery. At that time Ht was 31%, Hb was 8.7 g·dl^{-1}, and blood platelet count was 158 × 10^3·μl^{-1}. We suppose that surgery without blood transfusion using CPB might not have been successful in this case.

In cases in which homologous blood transfusion is not performed, there may still be a risk of infection in heating the processed blood preparation for supplying serum protein. As simple deep hypothermia does not always cause extreme hemodilution, PPF should only be administered when excessive hypoproteinemia is found by hematological examination. Since reduction of TP may result in delay of wound healing and anasarca, ascites, or hydrothorax due to depression of colloid osmotic pressure, and reduction of Hb may attenuate oxygen transport ability, PPF and red blood cells should be administered when TP and Hb are lower than the allowed limits. In this study all patients could maintain more than 7.6 g·dl^{-1} of Hb and 4.3 g·dl^{-1} of TP, and no event was detected resulting from anemia and/or hypoproteinemia.

When Hb concentration and cardiac output are presumed to be 7 g·dl^{-1} and 100 ml·kg·min^{-1}, respectively, oxygen delivery is calculated to be 9.38 ml·kg·min^{-1} (1.34 × 7). As oxygen consumption is about 4 ml·kg·min^{-1}, the uptake:consumption ratio of oxygen is calculated to be 0.42. It is suggested that Hb concentration of 7 g·dl^{-1} does not disturb oxygen transport in the patient without cardiac failure. Postoperative mild disorder of the central nervous system in case 11 might have been caused by exceeding the time allowed for induced cardiac arrest.

In open-heart surgery with transfusion under simple deep hypothermia, 10 ml·kg^{-1} of LMWD is regularly infused. Since we intended in this study to perform open-heart surgery without homologous blood transfusion, we infused LMWD additionally to keep CVP at 10 mmHg and also maintain blood pressure, especially during rewarming. The total dose of LMWD was up to 13.1 ± 2.9 ml·kg^{-1}. The use of a sympathetic nerve blocker is beneficial to prevent shivering and to maintain normal peripheral blood circulation, but the synergistic effect of rewarming and the action of the sympathetic nerve blocking agent causes dilatation of the vascular bed, because the agent remains active during the rewarming process. A large amount of colloid solution is therefore necessary to reverse the relative hypovolemia caused by this dilatation. In our study, we gave an adequate supply of ether by inhalation and administered PGE_1 to dilate arterioles only during the cooling. Since sympathetic nerve blockers that are longer-acting than PGE_1 were not administered during anesthesia, relative hypovolemia causing vascular bed expansion did not occur, and optimal CVP and ABP could be maintained. These are important points in the performance of open-heart surgery without homologous blood transfusion under simple deep hypothermia.

Open-heart surgery under simple deep hypothermia has been performed on many infants and small children with congenital heart disease, including one underweight neonate of 2.5 kg [8–10]. The target diseases for open-heart surgery without homologous blood transfusion using simple deep hypothermia should be congenital simple cardiac defects such as ASD, VSD, tetralogy of Fallot, coarctation or interruption of the aorta, and TAPVR, because in these diseases intracardiac repair can be completely performed in about 60 min at 20°C body temperature.

We believe that simple deep hypothermia is more beneficial than CPB for open-heart surgery without homologous blood transfusion in infants and small children.

We conclude as follows:

1. Open-heart surgery without homologous blood transfusion was performed under simple deep hypothermia on 13 patients with congenital heart disease.
2. The minimum body weight of the patients was 2.5 kg.
3. Hb concentration and TP after surgery could be maintained at more than 7.6 $g \cdot dl^{-1}$ and 4.3 $g \cdot dl^{-1}$, respectively, and no event could be detected resulting from anemia and/or hypoproteinemia.
4. The decrease in blood platelet count after surgery was very small.
5. Simple deep hypothermia is good for open-heart surgery without blood transfusion for small children, infants, and neonates.

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