The Importance of Colloid Osmotic Pressure during Open Heart Surgery in Infants

Kiyoshi Haneda, Shigekazu Sato, Eiji Ishizawa and Togo Horiuchi

Department of Thoracic and Cardiovascular Surgery, Tohoku University School of Medicine, Sendai 980

Haneda, K., Sato, S., Ishizawa, E. and Horiuchi, T. The Importance of Colloid Osmotic Pressure during Open Heart Surgery in Infants. Tohoku J. exp. Med., 1985, 147 (1) 65-71 — Fifty-five infants with transposition of the great arteries and with total anomalous pulmonary venous return underwent intracardiac repair under combined surface/perfusion hypothermia and total circulatory arrest in 1975 to 1983. Although cardiopulmonary bypass (CPB) time is limited when hypothermic circulatory arrest is employed, fluid balance derangement is one of the major postoperative complications. Fluid balance at the end of CPB averaged +299.5 ml (+63.4 ml/kg) when hemodilution with lactated Ringer’s was utilized (Group A). Since colloid osmotic pressure (COP) plays an important role in regulating fluid balance, colloid hemodilution prime (whole blood and plasma) was employed in the last 3 years (Group B). COP and total protein concentration during CPB with colloid prime were maintained at around 19 mmHg and 5 g/100 ml, respectively. In Group B, fluid balance at the end of CPB averaged +81.1 ml (+16.3 ml/kg) and was significantly less than in Group A (p<0.01). The ICU stay period for survivors in Group B (average 10.9 days) was reduced to half the period in Group A (average 20.6 days) (p<0.05). The mortality rate in Group A was 42%, whereas 23% in Group B. It was concluded that well-maintained COP levels during CPB with colloid hemodilution prime reduced fluid accumulation in the body and made patient care easier following open heart surgery in infants.

Colloid osmotic pressure; open heart surgery in infants; induced hypothermia

From January 1969 to December 1984, 205 infants in their first year of life underwent open heart surgery at our institution. One hundred and fifty-six of them were operated on under combined surface/perfusion hypothermia and total circulatory arrest. Despite recent advancements in diagnostic ability, surgical techniques and patient managements during perioperative period, there remain several problems in open heart surgery for infants. Fluid balance derangement is one of the major postoperative complications because fluid often leaks from intra-to extravascular space during cardiopulmonary bypass (CPB). Since colloid

Received February 27, 1985; accepted for publication June 12, 1985.
osmotic pressure (COP) plays an important role in regulating fluid balance, in the last 4 years we have used colloid hemodilution prime in order to maintain adequate COP levels during CPB. This has resulted in diminished fluid accumulation in the body.

This report describes the effect of colloid hemodilution prime on the operative consequence following open heart surgery using hypothermic circulatory arrest in infants.

**MATERIALS AND METHODS**

Fifty-five infants (less than 12 months) with transposition of the great arteries (TGA) and with total anomalous pulmonary venous return (TAPVR) who underwent intracardiac repair between 1975 and 1983 were divided into 2 groups according to the year of operation. Group A consisted of 33 infants (18 TGA and 15 TAPVR) operated during 1975 to 1980, whereas Group B consisted of 22 infants (12 TGA and 10 TAPVR) during 1981 to 1983. Age and body weight at the time of surgery in Groups A and B were 5.7±3.1 months (mean±s.d.) vs 3.0±3.0 months ($p<0.02$) and 5.4±1.4 kg vs 4.7±1.7 kg, respectively. Intracardiac repair was performed by means of combined surface/perfusion hypothermia and total circulatory arrest in all patients.

Anesthesia was induced with halothane and nitrous oxide in oxygen following administration of atropine or scopolamine (0.01-0.02 mg/kg), then was maintained with ether in 100% $O_2$ through a semi-closed circuit. Surface cooling was by ice-water immersion via a plastic sheet interposed between the patient and a water bath. During surface cooling, 10% of low molecular weight dextran (1 g/kg) was administered in order to improve microcirculation and prevent hemoconcentration. Surface cooling was terminated at the esophageal temperature of 27°C to allow median sternotomy (Fig. 1). After systemic heparinization, an arterial cannula was inserted into the ascending aorta and a single venous cannula into the right atrial appendage. CPB was initiated at 23°C and maintained at the arterial flow

![Fig. 1. Hypothermia course.](image)
Colloid Osmotic Pressure during Open Heart Surgery

rate of 120-140 ml/kg/min. The rate of perfusion cooling was regulated by controlling the temperature drop to 2°C/5 min in order to avoid rapid cooling. Circulation was arrested at 16-18°C and cardioplegia was induced with cold Young’s solution* injected directly into the aortic root. During the arrest period venous blood was allowed to gravity drain into a reservoir and recirculate within the closed extracorporeal system. After completion of the repair, CPB was restarted to rewarm the infant to 34°C with the aid of surface rewarming.

The extracorporeal circuit consisted of a Bentley bubble oxygenator (Temptrol Q-130) with a Brown-Harrison heat exchanger in Group A, and a Sci-Med Kolobow membrane oxygenator (Model 0800-2A) with an Omnitherm heat exchanger in Group B. In Group A, the system was primed with whole blood, lactated Ringer’s solution and with or without fresh frozen plasma to provide a hematocrit of 20-25% (Table 1). On the other hand, colloidal hemodilution with whole blood and fresh frozen plasma to provide a hematocrit of 25 to 30% was used in Group B. Twenty percent of mannitol (1 g/kg) was administered during perfusion cooling in both groups.

The COP of Group B patients was measured with a colloid osmometer (Wescor Inc., Model 4100) at room temperature.

Data between the 2 groups were compared with Student’s t-test, and statistical difference was considered to be significant when \( p < 0.05 \).

**Table 1. Priming solution for perfusion system**

<table>
<thead>
<tr>
<th></th>
<th>Whole blood</th>
<th>Lactated Ringer’s</th>
<th>Plasma</th>
</tr>
</thead>
<tbody>
<tr>
<td>Group A</td>
<td>400–600 ml</td>
<td>400–700 ml</td>
<td>0–240 ml</td>
</tr>
<tr>
<td>Group B</td>
<td>800</td>
<td>—</td>
<td>240–320</td>
</tr>
</tbody>
</table>

Crystalloid solution was eliminated from the pump prime in Group B.

*Young’s solution: 0.81 g potassium citrate, 2.46 g magnesium sulfate, 0.001 g neostigmine methyl sulfate, \( \text{H}_2\text{O} \) q.s. to 100 ml and pH adjusted to 7.4 with \( \text{NaHCO}_3 \).
RESULTS

There were no significant differences in esophageal temperature at circulatory arrest (17.8 ± 1.3°C vs 16.8 ± 2.0°C; mean ± s.d.), period of total circulatory arrest (56.5 ± 13.0 min vs 57.2 ± 12.4 min) and CPB time (66.7 ± 23.5 min vs 66.2 ± 41.3 min) between Groups A and B (Fig. 1).

Hematocrit levels during CPB in Group B were maintained at around 29%
Colloid Osmotic Pressure during Open Heart Surgery

and were significantly greater than in Group A where hematocrit levels were 18 to 23% (Fig. 2). In Group B, COP and total protein concentration were measured throughout the entire procedure and maintained at around 19 mmHg and 5 g/100 ml during CPB (Fig. 3).

Fluid balance at the end of CPB averaged +299.5 ml (+63.4 ml/kg) in Group A and +81.1 ml (+16.3 ml/kg) in Group B (p <0.01) (Fig. 4). In comparing the ICU stay period for survivors, the period for Group B was reduced to half the period for Group A (average 20.6 days in Group A vs 10.9 days in Group B. p <0.05) (Table 2). The mortality rate in Group A was 42% as against 23% in Group B, however, the difference was not significant statistically.

**DISCUSSION**

Fluid shift from intra- to extravascular space is explained by Starling's equilibrium theory (Starling 1896). Capillary filtration pressure, COP gradients across capillary and capillary permeability are the determinants of fluid volume in the interstitial spaces. Furthermore, lymph flow also affects the interstitial fluid volume. Although many factors associated with CPB, deep hypothermia and total circulatory arrest have been documented to affect fluid balance (Cohn et al. 1971; Chen and Chien 1977; Pang et al. 1979; Chen et al. 1980; Rosenkranz et al. 1980; Meretoja et al. 1981), decreased COP due to hemodilution should be considered to be one of the major determinants of fluid balance derangement following open heart surgery.

In comparing Groups A and B, there were no significant differences in degree of hypothermia, arrest period and CPB time. Differences in hypothermia technique between the 2 groups were (1) pump prime (with or without crystalloid solution) and (2) oxygenator (bubble vs membrane). Since the oxygenator does not directly affect fluid balance, significant differences in fluid balance at the end of CPB between the 2 groups must be caused by COP levels during CPB. COP was not measured for Group A. However, in our in vitro study, COP in priming solution which consisted of whole blood and lactated Ringer's demonstrated pressure below 11 mmHg (Table 3). The fluid volume in the extracorporeal circuit was about triple the blood volume of the infants. Therefore, COP levels

### Table 2. Postoperative results

<table>
<thead>
<tr>
<th>Group</th>
<th>ICU stay period*</th>
<th>Mortality rate</th>
</tr>
</thead>
<tbody>
<tr>
<td>Group A</td>
<td>20.6±14.1 days</td>
<td>42% (14/33)</td>
</tr>
<tr>
<td></td>
<td>p&lt;0.05</td>
<td>NS</td>
</tr>
<tr>
<td>Group B</td>
<td>10.9 ± 8.5</td>
<td>23 (5/22)</td>
</tr>
</tbody>
</table>

* ICU stay period in survivors (mean±s.d.).

Group B demonstrated significantly shorter ICU stay period and a tendency of decrease in mortality rate compared with Group A.
during CPB using a crystalloid hemodilution could be significantly lower than normal values (21.6±3.6 mmHg; Weil et al. 1974). Colloid hemodilution in Group B, on the other hand, resulted in COP levels within normal range during CPB and in significantly less fluid accumulation in the body.

The colloid-hydrostatic pressure gradient (COP-pulmonary artery wedge pressure) is clinically used as an indicator of pulmonary edema, and it has been reported that pulmonary edema easily develops when the gradient is less than 1-4 mmHg (Da Luz et al. 1975; Morissette 1977; Lundsgaard-Hansen and Pappova 1981; Duncan and Young 1982). Since wedge pressure progressively increases as body temperature decreases because of depressed myocardial function or compliance (Haneda et al. 1982), the colloid-hydrostatic pressure gradient tends to decrease with cooling. Most infants who require open heart surgery early in life have some degree of respiratory problems preoperatively. Maintenance of adequate levels of COP during hypothermia procedures, therefore, could have significant advantages in preserving lung function.

Although the mortality rate and ICU stay period were dependent on many factors such as the operative technique, the preoperative patient's condition etc., we concluded that well-maintained COP levels during CPB with colloid hemodilution prime reduced fluid accumulation in the body and made patient care easier following open heart surgery in infants.

**References**


