Prolonged Veno-Arterial Bypass with Membrane Oxygenator for Profound Cardiogenic Shock Following Cardiac Surgery
Experience in 13 Cases

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As a mechanical cardiac support, prolonged (over 5 hrs) Veno Arterial Bypass (VAB) with membrane oxygenator was indicated to 13 patients who was profound cardiogenic shock following open heart surgery, among 1700 cases of cardiac surgery (0.8%). In 12 of 13 cases, cardiopulmonary bypass could not be weaned after intracardiac repair, despite maximal pharmacological management with or without IABP support. Another one case was intractable ventricular fibrillation in ICU, two days after operation.

Six of 13 patients who were supported by prolonged VAB, survived and discharged from the hospital. In survivors, mean of VAB flow was $900 \pm 265$ ml/min/m$^2$, in died 7 cases, mean of VAB flow was $1450 \pm 550$ ml/min/m$^2$ ($p < 0.05$). The longest duration of VAB in survivors was less than 28 hrs.

Improvements of anticoagulation and VAB circuits make it safer to manage prolonged VAB. For profound cardiogenic shock, prolonged VAB is an easy and safe mechanical cardiac support not only in surgical cases but in internal medical cases.

PROLONGED (over 5 hrs) Veno Arterial Bypass (VAB) with membrane oxygenator is not familiar method, because of bleeding from the surgical wound and complicated management of extracorporeal circuits. However, hemodynamic effects of VAB are well known and most cardiac surgeons generally use short time VAB support, especially when patients can not be easily weaned from cardiopulmonary bypass (CPB) after intracardiac repair.

For prolonged VAB, we$^{1,2}$ improved two points; one is anticoagulation and another is VAB circuits. Continuous low-dose heparin with monitoring of heparin dose by ACT, reduced bleeding from surgical wound and significant bleeding of internal organs. Blood loss could be reduced by suctioning blood in the pericardial cavity and by return blood to VAB circuits. Air section from venous cannula could be prevented by servoregulated perfusion pump. These improvements made it easy and safe to manage prolonged VAB.

We used prolonged VAB for 13 patients of profound cardiogenic shock following open heart surgery in this 10 years, 6 of whom survived and discharged from the hospital. The purposes of this paper are to report patient series, prolonged VAB techniques and results.

Patients and Methods
Patient series (Table I)
The indications for prolonged VAB in 13 patients were profound cardiac failure following open heart surgery. In 12 of 13 cases, CPB for open heart surgery could not be weaned after intracardiac repair, despite maximal pharmacological management including noradrenaline-phenoxybenzamine$^3$ therapy, with or without

Key Words:
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<table>
<thead>
<tr>
<th>Case No.</th>
<th>Patient</th>
<th>Age/Sex</th>
<th>Diagnosis</th>
<th>Op. Procedure</th>
<th>Genesis of Shock</th>
<th>VAB Duration (hrs)</th>
<th>Flow Rate (ml/min/m²)</th>
<th>Outcome</th>
<th>Comments</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>O.T.</td>
<td>16/F</td>
<td>TF</td>
<td>radiol Op.</td>
<td>long run of CPB</td>
<td>22</td>
<td>1000</td>
<td>died</td>
<td></td>
</tr>
<tr>
<td>2</td>
<td>O.R.</td>
<td>9/F</td>
<td>AR</td>
<td>AVR</td>
<td>long run of CPB</td>
<td>11</td>
<td>2200</td>
<td>died</td>
<td>Cardiac arrest before CPB</td>
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<tr>
<td>3</td>
<td>K.T.</td>
<td>46/M</td>
<td>IHD</td>
<td>CAB</td>
<td>PMI</td>
<td>10</td>
<td>800</td>
<td>died</td>
<td>IABP, NOR-POB</td>
</tr>
<tr>
<td>4</td>
<td>T.I.</td>
<td>16/M</td>
<td>Ebstein</td>
<td>TVSI</td>
<td>intractable V.F.</td>
<td>5</td>
<td>1000</td>
<td>survived</td>
<td>Prolonged VAB in ICU</td>
</tr>
<tr>
<td>5</td>
<td>I.T.</td>
<td>29/M</td>
<td>TAPVR</td>
<td>radical Op.</td>
<td>long run of CPB</td>
<td>17</td>
<td>1000</td>
<td>died</td>
<td>NOR-POB</td>
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<tr>
<td>6</td>
<td>O.I.</td>
<td>52/M</td>
<td>AR, MR</td>
<td>AVR, MVR</td>
<td>PMI</td>
<td>22</td>
<td>800</td>
<td>survived</td>
<td>IABP, NOR-POB</td>
</tr>
<tr>
<td>7</td>
<td>O.S.</td>
<td>50/M</td>
<td>MR, TR</td>
<td>MVR, TAP</td>
<td>hypofunction of LV</td>
<td>28</td>
<td>900</td>
<td>survived</td>
<td>NOR-POB, Sudden death two years after Op.</td>
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<tr>
<td>8</td>
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<td>51/F</td>
<td>MSR, TR</td>
<td>MVR, TVSI</td>
<td>PMI</td>
<td>56</td>
<td>1800</td>
<td>died</td>
<td>NOR-POB, IABP, LVAD</td>
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<tr>
<td>9</td>
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<td>55/M</td>
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<td>CAB</td>
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<tr>
<td>10</td>
<td>N.A.</td>
<td>7/F</td>
<td>TGA (III)</td>
<td>Senning's Op.</td>
<td>long run of CPB</td>
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<td>600</td>
<td>survived</td>
<td>NOR-POB, Peritoneal Dialysis</td>
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<tr>
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<td>38/M</td>
<td>IHD (ASH)</td>
<td>CAB</td>
<td>PMI</td>
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<td>800</td>
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<td>52/M</td>
<td>IHD</td>
<td>CAB</td>
<td>PMI</td>
<td>19</td>
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<td>survived</td>
<td>IABP, NOR-POB</td>
</tr>
<tr>
<td>13</td>
<td>K.S.</td>
<td>51/F</td>
<td>AS, MS, TR</td>
<td>AVR, MVR, TVSI</td>
<td>long run of CPB</td>
<td>36</td>
<td>2000</td>
<td>died</td>
<td>IABP, NOR-POB</td>
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</table>

CPB = cardiopulmonary bypass; PMI = perioperative myocardial infarction; NOR-POB = Noradrenaline-phenoybenzamine; LAVD = left ventricular assist device; TVSI = tricuspid valve superimposition.
IABP support. In another case, ventricular fibrillation could not be resuscitated by manual cardiac massage in ICU, two days after operation. Patient age ranged from 7 years old to 55 years old and mean was 36 years old. Original cardiac diseases were congenital heart disease (5 cs), valvular heart disease (4 cs) and ischemic heart disease (4 cs).

Genesis of profound cardiogenic shock which required prolonged VAB, were intraoperative myocardial infarction (6 cs), long run of CPB (5 cs), cardiac hypofunction before operation (1 cs) and intractable ventricular fibrillation (1 cs).

Prolonged VAB Technique
Cannulation and extracorporeal circulation circuits are shown in Fig. 1. The venous cannula was inserted from the right atrium or the femoral vein, and the arterial cannula was inserted from the femoral artery. One suction cannula was placed in the pericardial cavity for suctioning blood from mediastinal wound, and these blood was pooled in the reservoir and drained to the venous tube. For preventing air suction which occurred from the venous cannula by excessive negative exsanguinating pressure, a servo-regulated pump control was equipped in the venous tube before the roller pump. Priming volume of these circuits including the heat exchanger and Kolobow membrane oxygenator, was approximately 800 ml. As usual, fresh blood containing 1000 units heparin per 200 ml of blood was used for priming the circuits.

Anticoagulation was maintained by an initial dose of 200 units per kg of heparin followed by continuous low-dose heparin infusion, to maintain the whole blood activated coagulation time (ACT) about 200 seconds. In general this averaged 20 to 30 units of heparin per kg per hour.

RESULTS
Six of 13 patients who was supported by prolonged VAB, survived and discharged from the hospital. One of these survivors died suddenly at his home two years after discharge, probably because of arrhythmia. Another five survivors are well and return to work or school.

Genesis of profound cardiogenic shock which required prolonged VAB were intraoperative myocardial infarction in 6 case, 3 of whom are survivors. However, only one of 5 cases whose genesis were long run of CPB for open heart surgery, could survive. Both cases of cardiac hypofunction before the operation and intractable ventricular fibrillation in ICU could survive.

In survived 6 cases, prolonged VAB flow rate when the patient arrived at ICU from operation room (OFR), ranged from 550 to 1330 ml/min/m² of body surface, and mean (M) ± standard deviation (SD) was 900 ± 265 ml/min/m². In died 7 cases, bypass flow rate
ranged from 770 to 2180, M ± SD was 1450 ± 550 ml/min/m² (p < 0.05).

Duration of prolonged VAB in survivors ranged from 5 hrs 15 min to 27 hrs 52 min, and mean duration was approximabley 20 hrs. In died cases, duration of bypass ranged from 10 hrs to 55 hrs 45 min. The longest duration in survivors was less than 28 hrs.

**Illustrative case Reports**

A typical case which was successfully weaned from prolonged VAB, a pediatric case and an unsuccessful case are presented.

Case 7. O.S. a 50-year-old male, was hospitalized in semi-Fowler position complaining recurrent rest dyspnea even with full medication. Dilatation of the jugular vein and hepatomegaly (6 cm under the costal margin) were observed. Finding of cardiac catheterization was as followed: LV 119/−9 (ED26), Ao 119/90

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(104). PA 75/45 and cardiac output was 2.0 L/min. According to left ventricular angiography, mitral regurgitation was 3 degree and ejection fraction was 36%. The operative procedure (MVR, TAP) was performed in October, 1979, however, during dripping of protamine hypotension followed ventricular fibrillation occurred. By supporting of VAB, the heart could be resuscitated but bypass flow rate could not be reduced less than 1500 ml/min (900 ml/min/m²). After changing from a bubble oxygenator to a membrane oxygenator for prolonged VAB, the patient was moved to ICU from OPR with driving VAB circuits. In ICU, bypass flow rate was 900 ml/min/m², and blood pressure (BP), pulsat rate and urine output (U.O.) became stable. Twenty-three hrs after starting of VAB, bypass flow was able to decrease slowly for weaning.

Japanese Circulation Journal  Vol. 48, March 1984
VAB. However, during reduction of flow rate the patient became irritable and generalized rigidity, convulsion, cyanosis and hypotension occurred. Therefore, bypass flow was returned back to 900 ml/min/m² and noradreneline (NOR) phenoxyzbenzamine (POB) were administrated. Before NOR (1.0 γ/kg/min in initial dose) was administrated, POB (1 mg/kg) was dripped for 30 minutes. Thereafter, 28 hrs after starting of VAB, the patient could be successfully weaned from prolonged VAB. This experience showed that prolonged VAB was effective for profound cardiogenic shock causing left ventricular hypofunction (Fig. 2).

Case 10. N.A. a 7-year-old female was hospitalized with complaining general cyanosis and short of breathing. The diagnosis was TGA with VSD and infundibular & valvular PS. The operative procedure was Senning’s atrial switch operation, closure of VSD and release of PS. The pump run time of CPB was 4 hrs 44 min. After decannulation of CPB, BP became down to less than 50 mmHg of systolic pressure and DOP, DOB & NOR were not effective. Therefore, prolonged VAB was started by 900 ml/min of bypass flow, then fairly good hemodynamic state was obtained. After bypass flow rate could be reduced to 400 ml/min, the patient was removed from OPR to ICU. Twenty-two hrs after starting of VAB, the patient could be weaned from prolonged VAB. Peritoneal dialysis for acute renal failure was done everyday after weaning from VAB, for 5 days. She could be weaned from the respirator 12 days after operation and discharged from the hospital at 82th days (Fig. 3).

Case 8. M.H. 51 year-old female was hospitalized complaining exertional dyspnea and recurcuent congestive heart failure. She was undertaken closed mitral commissurotomy at 34 year-old. Dilatation of jugular veins and heptomegaly (7 cm under the costal margin) were observed and CTR in chest x-ray was 85%. Diagnosis was re-stenosis of mitral valve and severe tricuspid regurgitation. The operative procedure was mitral valve replacement (MVR) and tricuspid valve super imposition (TVSI) with using bioprosthesis. After intracardiac repair, ECG findings showed acute MI of antero-septal wall of LV. By administration of NOR (1 γ/kg/min), CPB could be weaned, however, low cardiac output consisted (BP: 75/55, LAP: 18 mmHg, CO: 2.0 L/min). Therefore, prolonged VAB was indicated and by 1000 ml/min of bypass flow hemodynamic conditions became stable. Nineteen hrs after starting of VAB, she could be transiently weaned from prolonged VAB by increase of NOR to 4.7 γ/kg/min. During the patient was moved from ICU to OPR to close the chest, cardiac arrest occurred and could not be resuscitated by manual cardiac massage. The heart was resuscitated by VAB (II) and bypass flow rate was necessary over 1800 ml/min (1200 ml/min/m²) for maintaining BP over 75 mmHg in systolic pressure. Although CVP and LAP were maintained over 20 mmHg, BP, urine output (UO) and P_{O_2} became gradually down. Forty-one hrs after starting of VAB, VAB was switched by left ventricular assist device (LVAD) and right ventricular assist device (RVAD). The venous cannula for LVAD was inserted from the left atrium through the right pulmonary vein and arterial cannula from the ascending aorta. With using LVAD, CVP and LAP came promptly down, and BP, UO and P_{O_2} became up. However, the patient’s heart itself deteriorated progressively and completely depended on LVAD. At the same time generalized edema became more prominent, so LVAD was stopped 52 hrs after starting of LVAD (Fig. 4, 5).

**DISCUSSION**

When the patient can not be weaned from
cardiopulmonary bypass for open heart surgery, IABP or short term VAB are usually used as a mechanical cardiac support. Among 1700 cs of open heart surgery in our hospital, IABP or and prolonged VAB were indicated for 25 patients (1.5%) who could not be weaned from CPB. With only IABP support for 13 patients, 8 cases could be weaned from CPB, and 7 cases could discharge from the hospital. With prolonged VAB with or without IABP for 12 patients, five cases could be weaned from prolonged VAB and discharge from the hospital (Fig. 6). In recent years, operative results of open heart surgery are getting improved and low cardiac output after cardiac surgery fairly decrease in number, mainly because of improvements of myocardial protection during open heart surgery. As operative risk become low, more severe, elder and complicated patients become to be indications of cardiac surgery. Therefore, mechanical cardiac supports are still essential for cardiac surgery.

The hemodynamic effects of VAB are well recognized generally for cardiac surgeons and most surgeons usually use short term VAB using CPB circuits, especially when patients can not be easily weaned from CPB. Although preload of the heart can be decreased by VAB, afterload of the heart must be increased simultaneously with increasing of whole body perfusion flow by VAB. This increment of afterload is a demerit for the heart in a point of emergency consumption of the heart, but coronary perfusion flow increases certainly and it may compensate the demerit. Increment of whole body perfusion flow by VAB improves the peripheral tissue perfusion and metabolic acidosis. According to Takamoto,10 increments of whole body perfusion flow were 3% by using IABP, 18% by using VAB (bypass flow rate was one-third of cardiac output) and 25% by using VAB with IABP. Therefore, when cardiac output is very low like less than 2.0 L/min with 20 mmHg of LA pressure, IABP is not effective and in that case VAB is indicated for mechanical support. According to Wakabayashi VAB without oxygenator were effective for 5 cases in 6 patients who were severe cardiogenic shock following acute MI. VAB was indicated for the patients who were cardiogenic shock, before and after cardiac surgery.

Prolonged VAB with membrane oxygenator is not familial method as a mechanical cardiac support after cardiac surgery, because of bleeding from the surgical wound and complicated management of extracorporeal circulation circuits. Anticoagulation was maintained by an initial dose of 200 units per kg of heparin followed by continuous low-dose heparin infusion, to maintain ACT about 200 seconds5. Blood loss from surgical wound could be reduced and significant bleeding of internal organs was not observed after introduction of this admission method of heparin. An equipment of a servo-regulated perfusion control for preventing air suction from the venous cannula, make it easy and safe to manage the extracorporeal circulation circuits. By these improvements, prolonged VAB became to be a safer mean as a mechanical cardiac support.

According to our experiences, it is a indication of prolonged VAB that the patient can not be weaned from CPB even with IABP support and maximal pharmacological managements. As prolonged VAB become to be a safer method, the indication may be extend to profound shock which occures suddenly by acute MI or massive pulmonary embolism not only in surgical ward but in internal medical ward.

REFERENCES

Japanese Circulation Journal Vol. 48, March 1984