Factors for Successful Weaning From a Percutaneous Cardiopulmonary Support System (PCPS) in Patients With Low Cardiac Output Syndrome After Cardiovascular Surgery

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SUMMARY

The objective of this study was to analyze the early predictive factors for successful weaning from a percutaneous cardiopulmonary support system (PCPS) in patients with low cardiac output syndrome after cardiovascular surgery.

A total of 938 patients underwent cardiovascular surgery with cardiopulmonary bypass (CPB) from January 1991 to September 2006 at Gunma University Hospital. Of these 938 patients, 13 (1.4%) required PCPS to maintain hemodynamics within 48 hours after surgery. The mean age of the 13 patients was 66 years (range, 45 to 86 years). Nine patients underwent open-heart surgery, 3 repair of a thoracic aortic aneurysm, and 1 a pericardectomy. The patients were divided into 2 groups; group A (n = 4) who were removed from PCPS and group B (n = 9) who were not removed from PCPS. The conditions during the operation and after PCPS support were compared between the 2 groups.

The mean age was higher, and operation time, CPB time, and aortic cross-clamping time were significantly (P < 0.05) longer in patients with PCPS than in those without PCPS. The mean PCPS time in all 13 patients was 190 ± 122 hours. The mean age was higher, and CPB time and the aortic cross-clamping time were longer in group B than in group A (NS). The mean duration of PCPS support was significantly (P < 0.05) shorter in group A than in group B (117 ± 42 hours versus 235 ± 136 hours). PCPS flow in group A could be reduced from 48 hours after PCPS induction. However, PCPS flow in group B could not be reduced, and there were significant (P < 0.05) differences in PCPS flow at 72 and 96 hours after starting PCPS. Significant (P < 0.05) differences in the absolute values of the APACHE II score, serum lactate levels, administered epinephrine dose, and levels of total bilirubin (T-Bil), serum creatinine (sCr), and lactate dehydrogenase (LDH) were found between the 2 groups within 96 hours after PCPS induction. In addition, there were significant (P < 0.05) differences in the rate of change compared with the baseline control value obtained prior to PCPS use in PCPS flow, APACHE II score, and levels of T-Bil, sCr, and LDH within 96 hours after PCPS induction. Significant differences in the rate of change of sCr and LDH were found, especially from the early phase after PCPS use, compared with other parameters.

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Received for publication May 22, 2007.

Revised and accepted September 14, 2007.
In the patients removed from PCPS, PCPS flow could be reduced within 48 hours after commencement of PCPS. Improvements in the APACHE II score and biochemical variables within 96 hours appear to be reliable prognostic factors for PCPS patients. (Int Heart J 2007; 48: 743-754)

**Key words:** Cardiovascular surgery, Low output syndrome, Circulatory support, Percutaneous cardiopulmonary support (PCPS)

CARDIOVASCULAR surgery with cardiopulmonary bypass (CPB) is widely and safely performed because of advances in operative procedures, cardioplegia, preoperative management, and anesthesia techniques. However, postoperative heart failure occurs in some cases, and mechanical support for the circulation may be required in patients with acute postoperative heart failure which is resistant to inotropic treatment. If left ventricular dysfunction is not severe, intra-aortic balloon pumping (IABP) support can be an effective therapy; however, this is not efficacious enough in cases of severe ventricular dysfunction combined with pulmonary insufficiency.1)

The percutaneous cardiopulmonary support system (PCPS) is widely employed for severe heart failure, and its efficacy has been reported in patients with low cardiac output syndrome after cardiovascular surgery; this may be because of its simple initial setup and immediate support for both cardiac and pulmonary failure patients.2,3) In spite of this therapeutic support, the rates of mortality and morbidity in such patients are still high.3) In addition, long-term use of PCPS is limited because of a number of complications such as limb ischemia, decreased platelet count, and bleeding tendency due to anticoagulant administration.4)

In this retrospective study, we analyzed data from patients who required PCPS to determine early predictive factors for successful weaning from PCPS in patients with low cardiac output syndrome after cardiovascular surgery.

**METHODS**

A total of 938 patients underwent cardiovascular surgery with CPB between January 1991 and September 2006 at Gunma University Hospital. Thirteen patients (1.4%) required PCPS within 48 hours after surgery to maintain hemodynamic stability. The indication for PCPS for severe cardiac failure in our hospital is as follows: 5) peak systolic pressure of less than 80 mmHg and a cardiac index of less than 1.8 L/min/m² for more than 30 minutes after correction for hypovolemia, hypoxemia, and acidosis. A decrease in cardiac output unresponsive to intra-aortic balloon pumping (IABP), and patients in whom CPB could not be
The decision to initiate PCPS therapy was made by the attending physician. The PCPS system was comprised of a hollow-fiber microporous membrane oxygenator, a heat exchanger, a centrifugal pump, arterial and venous cannulae, and standard 3/8-inch tubing. The blood-contact surfaces of these components were heparin-coated. PCPS was established with venous drainage (19.5Fr or 21Fr) from the femoral vein (the tip of the tube was placed in the right atrium) and arterialized blood was returned to the femoral artery using a 15Fr or 16.5Fr arterial cannula. In recent practice, we have been using a Capiox SP Pump Controller Sp-101 and a Capiox circuit (Terumo Co., Tokyo). PCPS flow was initially maintained in the range of 2.0 to 2.5 L/min/m² and activated clotting time was maintained at 150 - 250 seconds with the administration of nafamostat mesylate, a potent antiplatelet agent, during PCPS. The protocol for the termination of PCPS is as follows: PCPS flow was gradually decreased with enough preload and administration of catecholamines for stabilization of the hemodynamics. PCPS was terminated when PCPS flow was between 1.5 and 2.0 L/min and hemodynamic stability was attained, ie, systolic blood pressure was more than 80 mmHg, central venous pressure was less than 15 mmHg, and pulse pressure was more than 30 mmHg.

Of the 13 patients who underwent PCPS, 10 were men and 3 were women. The mean age was 66 ± 11 years (range, 45 to 86 years). The surgical procedures are shown in Table I. Six (46%) patients underwent emergency operations.

**Table I. Surgical Procedures**

<table>
<thead>
<tr>
<th>Procedure</th>
<th>Group A</th>
<th>Group B</th>
</tr>
</thead>
<tbody>
<tr>
<td>(E) Patch closure for VSP (VSP/AMI)</td>
<td>2 (1, 1)</td>
<td>2 (1, 1)</td>
</tr>
<tr>
<td>(E) MVR+LV plasty (LV rupture/AMI)</td>
<td>1 (1)</td>
<td>1 (1)</td>
</tr>
<tr>
<td>(E) Aortic root replacement (AAD DeBakey I)</td>
<td>1 (1)</td>
<td>1 (1)</td>
</tr>
<tr>
<td>(E) Aortic arch replacement</td>
<td>2 (2)</td>
<td>1 (1)</td>
</tr>
<tr>
<td>(AAD DeBakey I, aneurysm rupture)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>reCABG</td>
<td>1 (1)</td>
<td></td>
</tr>
<tr>
<td>CABG+Dor operation</td>
<td>1 (1)</td>
<td>1 (1)</td>
</tr>
<tr>
<td>CABG+MVR+Dor operation</td>
<td>1 (1)</td>
<td></td>
</tr>
<tr>
<td>Pericardietomy for CP</td>
<td>1 (1)</td>
<td>1 (1)</td>
</tr>
<tr>
<td>Ebstein+ASD</td>
<td>1 (1)</td>
<td></td>
</tr>
<tr>
<td>AVR</td>
<td>1 (1)</td>
<td>1 (1)</td>
</tr>
<tr>
<td>AVR+MVR</td>
<td>1 (1)</td>
<td></td>
</tr>
</tbody>
</table>

VSP indicates ventricular septal perforation; AMI, acute myocardial infarction; MVR, mitral valve replacement; LV, left ventricle; AAD, acute aortic dissection; CABG, coronary artery bypass grafting; CP, constrictive pericarditis; ASD, atrial septal defect; and AVR, aortic valve replacement. (E) means emergency operation.
The patients were divided into the 2 groups: those who were successfully weaned from PCPS and discharged from the ICU (group A, \( n = 4 \)), and those who could not be weaned from PCPS and eventually died from multiple organ failure (MOF, \( n = 7 \)) or persistent cardiac failure (\( n = 2 \)) (group B, \( n = 9 \)). We compared the 2 groups with respect to age, duration of PCPS, length of stay in the ICU, use of IABP, and continuous hemodiafiltration (CHDF) and/or hemodialysis (HD). The PCPS flow, APACHE II score, urine output, serum lactate levels, dose of catecholamine (epinephrine, norepinephrine, dopamine, and dobutamine), and laboratory data from the start of PCPS to 96 hours after the start of PCPS, and the rates of change compared with the baseline control values obtained prior to PCPS use for these parameters were also compared between the 2 groups.

**Statistical analysis:** All results are expressed as the mean and standard deviation (SD). Statistical comparisons were made using \( \chi^2 \) analysis and repeated measure analysis of variance (ANOVA) followed by Fisher’s protected least significant difference. StatView software version 5.0 (Abacus, Berkeley, CA) was used for statistical analysis. A \( P \) value of less than 0.05 was interpreted as being statistically significant.

**RESULTS**

Table II shows the comparisons of age and mean time of operation, CPB, and aortic cross-clamping for patients with and without PCPS. There were statistically significant \( (P < 0.05) \) differences in age and mean time of operation, CPB, and aortic cross-clamping between the 2 groups.

The interval from end of the operation to PCPS induction was 5.8 hours and ranged from 0 hours to 48 hours. The mean PCPS time and ICU length of stay in 13 patients were 190 hours (range, 80 - 522 hours) and 25 days (range, 4 - 83 days), respectively. The mean duration of PCPS was significantly \( (P < 0.05) \) shorter in group A than in group B (Table III). There were no significant differ-

<table>
<thead>
<tr>
<th></th>
<th>With PCPS</th>
<th>Without PCPS</th>
<th>( P ) value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Age (y/o)</td>
<td>66 ± 11</td>
<td>55 ± 29</td>
<td>0.005</td>
</tr>
<tr>
<td>Mean operation time (min)</td>
<td>628 ± 322</td>
<td>430 ± 170</td>
<td>0.047</td>
</tr>
<tr>
<td>Mean CPB time (min)</td>
<td>373 ± 237</td>
<td>195 ± 98</td>
<td>0.025</td>
</tr>
<tr>
<td>Mean aortic-cross clamping time (min)</td>
<td>162 ± 48</td>
<td>109 ± 55</td>
<td>0.005</td>
</tr>
</tbody>
</table>

CPB indicates cardiopulmonary bypass.
ences in age, operation time, CPB time, aortic cross-clamping time, ICU length of stay, use of IABP and CHDF and/or HD in the 2 groups.

PCPS flow in group A could be reduced from 48 hours after PCPS start. On the other hand, PCPS flow in group B could not be reduced, and there were significant ($P < 0.05$) differences in PCPS flow at 72 and 96 hours after PCPS start between the 2 groups (Figure 1A). There was no significant difference in the APACHE II score before PCPS between the 2 groups. However, APACHE II scores in group A were significantly ($P < 0.05$) lower at 24, 48, and 72 hours after

Table III. Comparisons Between Group A and B

<table>
<thead>
<tr>
<th></th>
<th>Group A ($n = 4$)</th>
<th>Group B ($n = 9$)</th>
<th>$P$ value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Age (y/o)</td>
<td>$61 \pm 12$</td>
<td>$69 \pm 10$</td>
<td>0.291</td>
</tr>
<tr>
<td>Mean operation time (min)</td>
<td>$552 \pm 249$</td>
<td>$681 \pm 370$</td>
<td>0.468</td>
</tr>
<tr>
<td>Mean CPB time (min)</td>
<td>$326 \pm 131$</td>
<td>$421 \pm 295$</td>
<td>0.479</td>
</tr>
<tr>
<td>Mean aorta-clamping time (min)</td>
<td>$183 \pm 49$</td>
<td>$153 \pm 561$</td>
<td>0.382</td>
</tr>
<tr>
<td>Mean duration of PCPS support (hr)</td>
<td>$117 \pm 42$</td>
<td>$235 \pm 136$</td>
<td>0.049</td>
</tr>
<tr>
<td>Mean ICU length of stay (days)</td>
<td>$41 \pm 25$</td>
<td>$14 \pm 13$</td>
<td>0.069</td>
</tr>
<tr>
<td>Use of IABP (%)</td>
<td>$100$</td>
<td>$63$</td>
<td>0.080</td>
</tr>
<tr>
<td>Use of CHDF/HD (%)</td>
<td>$60$</td>
<td>$88$</td>
<td>0.355</td>
</tr>
</tbody>
</table>

CPB indicates cardiopulmonary bypass; ICU, intensive care unit; IABP, intra-aortic balloon pumping; CHDF, continuous hemodiafiltration; and HD, hemodialysis.

Figure 1. A: PCPS flow in the two groups. B: APACHE II score in the two groups.
PCPS start than those in group B (Figure 1B).

Urine output in group A gradually increased for 48 hours after PCPS start and stayed at more than 50 mL/hr after start of PCPS. On the other hand, urine output in group B was less than 50 mL/hr in spite of PCPS use (Figure 2A). When PCPS was started, blood lactate levels were high in both groups; however, blood

![Graph A: Urine Output](image1)

![Graph B: Blood Lactate Levels](image2)

**Figure 2.** A: Urine output in the two groups. B: Blood lactate levels in the two groups.

![Graph A: Epinephrine Dose](image3)

![Graph B: Norepinephrine Dose](image4)

**Figure 3.** A: Epinephrine dose in the two groups. B: Norepinephrine dose in the two groups.
lactate levels in group A gradually decreased and there was a significant difference ($P < 0.05$) between the 2 groups at 96 hours after start of PCPS (Figure 2B).

The doses of epinephrine and norepinephrine were gradually reduced in group A, however, the doses were not reduced in group B (Figure 3).

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**Figure 4.** A: LDH levels in the two groups. LDH indicates lactate dehydrogenase. B: Total bilirubin levels in serum in the two groups.

**Figure 5.** A: BUN levels in the two groups. BUN indicates blood urea nitrogen. B: Serum creatinine levels in the two groups.
no significant differences in the doses of dopamine and dobutamine administered between the 2 groups (data not shown).

Lactate dehydrogenase (LDH) levels in the 2 groups were not different before PCPS. However, LDH levels in group B gradually increased and the mean LDH level was significantly \( (P < 0.05) \) higher than in group A at 96 hours after start of PCPS (Figure 4A). Total bilirubin (T-Bil) also increased gradually in group B for 96 hours after PCPS start. On the other hand, there was no increase in group A, and there were significant differences \( (P < 0.05) \) between the 2 groups at 72 and 96 hours after PCPS start (Figure 4B).

There was no significant difference in blood urea nitrogen (BUN) levels between the 2 groups (Figure 5A). Serum creatinine (sCr) levels gradually increased in group B, and there was a significant difference \( (P < 0.05) \) between the 2 groups at 72 hours after PCPS start (Figure 5B).

The rates of change in PCPS flow, APACHE II score, blood lactate levels, LDH levels, T-Bil levels, and sCr levels (because there were significant differ-

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**Figure 6.** Rates of change compared with the baseline control values obtained prior to PCPS start.
ences between the two groups in these parameters) compared with the baseline control value obtained prior to PCPS use are shown in Figures 6 and 7. There were no significant differences in the rate of change of the epinephrine dose between the two groups (data not shown). As shown in Figure 6A, the rate of change in PCPS flow gradually decreased and was significantly ($P < 0.05$) lower in group A than in group B at 72 and 96 hours after PCPS start. The rate of change of the APACHE II score decreased in group A at 72 hours after PCPS start with a significant ($P < 0.05$) difference (Figure 6B). The rate of change of blood lactate levels decreased gradually in group A (NS, Figure 6C). The rates of change of LDH, T-Bil, and sCr gradually increased in group B, and significant ($P < 0.05$) differences were found between the two groups within 96 hours after PCPS start (Figure 7A, 7B and 7C). As shown in Figure 7A and 7C, significant differences were observed, especially from the early phase after PCPS use (from 12 hours after PCPS use in the rate of change of sCr, and from 24 hours after PCPS use in

![Figure 6](image6.png)

![Figure 7](image7.png)

**Figure 7.** The rates of change compared with the baseline control values obtained prior to PCPS start.
the rate of change of LDH), and the differences between the two groups gradually became larger as time progressed.

**DISCUSSION**

There were statistically significant differences in PCPS flow, APACHE II score, blood lactate levels, epinephrine dose, and levels of LDH, T-Bil, and sCr from PCPS start to 96 hours after PCPS start between groups A and group B in this study. In addition, significant differences were also found in the rate of change of PCPS flow, APACHE II score, and levels of LDH, T-Bil, and sCr for 96 hours after PCPS start. Significant differences in the rate of change of sCr and LDH were seen, in particular from the early phase after PCPS use, and these differences between the two groups gradually increased with time. The data showed that the prognosis of the patients, in whom PCPS flow and catecholamine dose could not be reduced and serum chemistry associated with renal and/or hepatic function did not recover within 96 hours after the induction of PCPS, was poor. It might be also important to evaluate not only the absolute values of these parameters but also the percentage changes. In addition, the prognosis might be better if the improvements in sCr and LDH levels occurred from the early phase after PCPS induction. Sasaki and coworkers reported that hemodynamic parameters in patients weaned from PCPS showed remarkable improvement within 40 hours of the introduction of PCPS. They proposed that low output syndrome due to severe myocardial stunning, which is associated with prolonged CPB time and aortic cross-clamping time, occurred in patients requiring PCPS in the postoperative period. However, PCPS flow could be reduced from 48 hours after PCPS start, and PCPS could be finally discontinued if myocardial stunning was temporary and cardiac function was reversible. Our results also suggest that PCPS can not be discontinued in patients who do not recover from myocardial stunning within 96 hours after the induction of PCPS, and long-term circulatory support is necessary for the maintenance of hemodynamics. However, PCPS provides only partial cardiopulmonary support, and it is possible that MOF occurs in such patients because of inadequate tissue perfusion. In a previous study, we identified MOF as an independent predictor of fatal outcome in patients with severe heart failure. Morris, et al also reported that development of renal or hepatic dysfunction while patients were on PCPS was a factor associated with an increased probability of mortality in postoperative patients requiring PCPS. Hoskote, et al found that multiple organ system failure was a significant risk factor for poor outcome among the nonsurvivors receiving PCPS after surgery in functional single ventricle patients. Many studies have shown that renal failure is an independent predisposing factor for increased mortality. Therefore, if the hemo-
dynamics of a patient cannot be improved with PCPS and if PCPS flow can not be reduced at most by 96 hours after the induction of PCPS, it may be difficult to wean them from PCPS, and other cardiac support such as a ventricular assist device (VAD) and/or heart transplantation may be required in such patients. Although the patient population was limited in this study, the results suggested that hemodynamic status and serum chemistry data for 96 hours after start of PCPS (not only the absolute values but also the rate of change compared with the baseline control value obtained prior to PCPS start) were reliable prognostic factors for successful weaning from PCPS in patients with low cardiac output syndrome after cardiovascular surgery.

In conclusion, in patients requiring PCPS to maintain hemodynamics after cardiovascular surgery with CPB, PCPS flow was reduced from 48 hours after PCPS start in patients that could be removed from PCPS. On the other hand, the prognosis may be poorer if PCPS flow can not be reduced and serum chemistry associated with renal and/or hepatic function does not recover within 96 hours after commencement of PCPS.

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