Factors for Weaning From a Percutaneous Cardiopulmonary Support System (PCPS) in Patients With Severe Cardiac Failure

A Comparative Study in Weaned and Nonweaned Patients

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SUMMARY

The percutaneous cardiopulmonary support system (PCPS) has been widely accepted for the treatment of patients with severe cardiac failure. This system, which uses Seldinger's method through a percutaneous approach, enables rapid application in emergency situations. However, the indication for deployment and discontinuation of PCPS has not yet been established. We evaluated the results of PCPS use for the treatment of patients with severe cardiac failure and investigated factors that would predict successful weaning from PCPS.

A total of 32 patients (23 men and 9 women) who had PCPS for the treatment of severe cardiac failure between January 1997 and October 2004 were retrospectively reviewed. The mean age of the patients was 57 ± 17 years (range, 14 to 78 years). PCPS was necessary for severe cardiac failure after cardiac surgery in 15 patients, pulmonary infarction in 4, acute myocardial infarction in 3, acute myocarditis in 3, and other causes in 7.

The mean duration of PCPS support in all 32 patients was 134 ± 117 hours (range, 8 to 532). Twelve patients (38%) could be weaned from PCPS (group A), while the remaining 20 patients (62%) could not (group B). The incidence of cardiac arrest prior to PCPS use ($n = 10$, 31%) was significantly ($P < 0.05$) lower in group A (1/12, 8%) than in group B (9/20, 45%). There were significant differences in the APACHE II scores, urine output, serum lactate levels, and epinephrine and dopamine dose received from PCPS induction to 72 hours after PCPS use between the 2 groups ($P < 0.05$). Multivariate logistic regression analysis showed that an episode of cardiac arrest prior to PCPS induction was the only significant predictor for the unsuitability for discontinuation of PCPS.

This retrospective study showed the limitation of PCPS therapy for patients with an episode of cardiac arrest who did not show improvement in their APACHE II score, urine output, serum lactate levels, and catecholamine dose received within 72 hours after PCPS induction. These results may help formulate criteria for indication and discontinuation of

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THE percutaneous cardiopulmonary support system (PCPS), which can supply hemodynamic volume assistance, was first described by Phillips and coworkers in 1983.¹⁾ Subsequently, favorable results²⁾ and remarkable advances in catheters and membrane oxygenators have resulted in the wide acceptance of this approach for circulatory support. Therefore, PCPS has been widely used for severe cardiac failure, cardiogenic shock, and/or postoperative cardiac support.³⁻⁵⁾ Recently, a heparin-coated PCPS circuit including centrifugal pump and membrane oxygenator has been established, and PCPS can be started easily and quickly with this circuit. However, some PCPS patients cannot be easily weaned from its support. In addition, clinical problems associated with PCPS such as left ventricular afterload, limb ischemia, decreased platelet count, bleeding, inguinal infection and complications of multiple organ failure (MOF) have been reported.⁶⁾ Such being the case, the indications for starting and discontinuing PCPS use remain a clinical problem.

In this retrospective study, we reviewed patients in whom PCPS was used for the treatment of severe cardiac failure, in order to determine factors that would predict the suitability of weaning from PCPS.

METHODS

The medical records of patients treated with PCPS in the Intensive Care Unit (ICU) of Gunma University Hospital between January 1997 and October 2004 were retrospectively reviewed. The indication for PCPS for severe cardiac failure in our hospital is as follows: peak systolic pressure less than 80 mmHg and cardiac index less than 1.8 L/min/m² for more than 30 minutes after the correction of hypovolemia, hypoxemia, and acidosis. Rapid deterioration of cardiac output unresponsive to intra-aortic balloon pumping (IABP) and patients in whom cardiopulmonary bypass could not be discontinued after cardiovascular surgery were also indications for the use of PCPS. The decision to initiate and continue PCPS therapy was made by the physicians in charge.

The PCPS system comprised 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 arterial blood basically returned to the femoral artery using a 15Fr or 16.5Fr arterial cannula. In recent practice, we have been using a Capiiox SP Pump Controller Sp-101 and Capiiox circuit (Terumo Co., Tokyo). PCPS flow was first maintained in the range 2.0 to 2.5 L/min/m², and activated clotting time was controlled to be 150-250 seconds with the administration of nafamostat mesilate during the period of PCPS use. With regards to the termination of PCPS, the PCPS flow was gradually decreased with sufficient preload and administration of the requisite dose of catecholamine after stabilization of the hemodynamics. When PCPS flow was between 1.5 and 2.0 L/min and hemodynamics were stable, 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, PCPS could be terminated.

In total, 32 patients were treated with PCPS for severe cardiac failure at the ICU of Gunma University Hospital between January 1997 and October 2004. Twenty-three were men and 9 were women. The mean age was 57 ± 17 (range 14 to 78) years. The clinical backgrounds of the 32 patients are shown in Table I. There were 15 patients who had undergone cardiovascular surgery using cardio-

Table I. Clinical Background of Severe Cardiac Failure Patients

Total patients without operation	: 17
Pulmonary infarction	: 4 (group A: 2, group B: 2)
Acute myocardial infarction	: 3 (group A: 2, group B: 1)
Acute myocarditis	: 3 (group A: 3)
Pulmonary hemorrhage	: 2 (group B: 2)
Chronic heart failure (ischemic)	: 1 (group B: 1)
Dilated cardiomyopathy	: 1 (group B: 1)
Others	: 3 (group B: 3)
(Anaphylaxis: 1, Thyroid crisis: 1, Cardiac failure with SLE: 1)	
Total postoperative patients	: 15
CABG	: 2 (group A: 2)
Patch closure for VSP	: 2 (group A: 1, group B: 1)
Aortic arch replacement	: 2 (group B: 2)
(AAD Stanford A :1, Rupture of aneurysm: 1)	
Ebstein+ASD	: 2 (group A: 1, group B: 1)
AVR	: 1 (group B: 1)
CABG + Dor operation	: 1 (group B: 1)
CABG + Dor + MVR	: 1 (group A: 1)
re-MVR	: 1 (group B: 1)
Dor + MVR	: 1 (group B: 1)
Pericardiectomy for CP	: 1 (group B: 1)
Aortic root replacement	: 1 (group B: 1)

SLE indicates systemic lupus erythematosus; CABG, coronary artery bypass grafting; VSP, ventricular septal perforation; AAD, acute aortic dissection; MVR, mitral valve replacement; and CP, constrictive pericarditis.

pulmonary bypass. Five cases underwent emergency operations; 2 ventricular septal perforations due to acute myocardial infarction, 2 aortic arch replacements (one case had rupture of a thoracic aortic aneurysm and the other had acute aortic dissection), and 1 coronary artery bypass grafting. All operations were successfully performed, however, preoperative cardiopulmonary resuscitation was required for the patient with acute aortic dissection. The remaining 17 patients did not undergo cardiovascular surgery.

The patients were divided into 2 groups: patients who were successfully weaned from PCPS and discharged from the ICU (group A), and patients who could not be weaned from PCPS and eventually died (group B). The 2 groups were compared with respect to age, gender, the mean duration of PCPS use and ICU stay, the use of IABP and continuous hemodiafiltration (CHDF), and whether or not the patient had cardiac arrest prior to PCPS induction. The PCPS flow, APACHE II score, urine output, serum lactate levels, and the dose of catecholamine used (epinephrine, norepinephrine, dopamine, and dobutamine) from PCPS start to 72 hours after starting were also compared between the 2 groups. Additionally, predictive factors for successful weaning from PCPS were investigated.

Statistical analysis: All results are expressed as the mean $\pm$ standard deviation (SD). Statistical comparisons were made using χ^2 analysis or analysis of variance (ANOVA) followed by Fisher's protected least significant difference. A multivariate logistic regression model was used to detect independent predictors of survival. StatView software version 5.0 (Abacus, Berkeley, CA) was used for statistical analysis. Statistical significance was assumed at a *P* value of less than 0.05.

Table II. Comparisons Between the Two Groups

	Group A (<i>n</i> = 12)	Group B (<i>n</i> = 20)
Age	54 $\pm$ 17	59 $\pm$ 17
Gender (M/F)	9/3	14/6
Mean duration of PCPS support (hours)	106 $\pm$ 80	141 $\pm$ 153
Mean duration of ICU stay (days)	24 $\pm$ 23	12 $\pm$ 13
Use of IABP (<i>n</i> = 24, 75%)	11 (92%)	13 (65%)
Use of CHDF (<i>n</i> = 22, 69%)	4 (33%) *	18 (90%)
Postcardiac surgery (<i>n</i> = 15, 47%)	4 (33%)	11 (55%)
Cardiac arrest prior to PCPS use (<i>n</i> = 10, 31%)	1 (8%)*	9 (45%)

Mean $\pm$ SD, **P* < 0.05.

ICU indicates intensive care unit and CHDF, continuous hemodiafiltration.

RESULTS

For all 32 patients, the mean duration of PCPS support and ICU stays were 134 ± 117 hours (range, 8-532 hours) and 15 ± 18 days (range 2-83 days), respectively. The mean cardiac index of all patients prior to the induction of PCPS was 1.56 ± 1.04 L/min/m². PCPS could be terminated in 12 patients (38%, group A). On the other hand, PCPS could not be terminated in 20 patients (62%, group B) and they died of the following causes; persistent cardiac failure in 9 (45% [9/20]), MOF in 8 (40% [8/20]), sepsis in 2 (10% [2/20]), and pulmonary bleeding in 1 (5% [1/20]).

Table II shows a comparison of various parameters between the 2 groups. The mean age and the mean duration of PCPS support were lower in group A than in group B; however, there were no significant differences between the 2 groups. There were 10 patients (31%) with cardiac arrest prior to the PCPS induction; 3 with pulmonary infarction, and 1 each with pulmonary hemorrhage, dilated cardiomyopathy, Dor operation combined with mitral valve replacement, acute aortic dissection, cardiac failure with systemic lupus erythematosus, anaphylaxis, and thyroid crisis, respectively. PCPS was removed only from a patient with pulmonary infarction. The incidence of cardiac arrest prior to PCPS induction was significantly lower ($P < 0.05$) in group A compared to group B. The interval from cardiac arrest to PCPS induction could not be evaluated in this study because the

Figure 1. A: Comparison of PCPS flow between the 2 groups. B: Comparison of APACHE II score between the 2 groups.

data were unclear in many patients. The number of patients with CHDF (22 patients, 69%) was also significantly lower ($P < 0.05$) in group A than in group B. The number of patients with IABP (24 patients, 75%) was higher in group A, and the number of patients after cardiac surgery (15 patients, 47%) was lower in group A; however, there were no significant differences between the 2 groups.

There were no significant differences between the 2 groups in the PCPS flow until 48 hours after start of PCPS. The PCPS flow in group A was significantly lower ($P < 0.05$) than in group B 72 hours after start of PCPS (Figure 1A). The APACHE II scores in group A were significantly lower ($P < 0.05$) than those in group B from the start of PCPS to 72 hours after the start of PCPS (Figure 1B). Urine output in group A increased gradually after the start of PCPS, and was significantly higher ($P < 0.05$) in group A than in group B 48 hours after PCPS induction (Figure 2A). There was no significant difference in serum lactate levels between the 2 groups prior to the start of PCPS. Serum lactate levels in group A decreased gradually, and were significantly lower ($P < 0.05$) than those in group B 24 hours after the start of PCPS (Figure 2B).

Figure 2. A: Comparison of urine volume between the 2 groups. B: Comparison of blood lactate levels between the 2 groups.

Figures 3 and 4 show the dose of catecholamine used (epinephrine, norepinephrine, dopamine, dobutamine). Patients in group B required higher doses of catecholamine for 72 hours after the start of PCPS, and there were significant differences ($P < 0.05$) in the amount of epinephrine and dopamine dose at some time points. There were no significant differences in the dose of norepinephrine and dobutamine between the 2 groups.

Prognosis of patients undergoing PCPS from the point of view of clinical factors prior to start of PCPS: The results of multivariate logistic regression analysis are shown in Table III. An episode of cardiac arrest prior to the start of PCPS was a significant factor related to termination of PCPS. The APACHE II scores, epinephrine dose, and serum lactate levels prior to starting PCPS were not related to removal from PCPS. Moreover, the result of stepwise regression analysis also indicated that cardiac arrest prior to starting PCPS was the most significant factor related to the prognosis of patients with PCPS ($R^2: 0.740$, $P < 0.0001$).

Complications: Lower limb ischemia occurred in 2 patients as a complication associated with the use of PCPS. In 1 patient, the contralateral femoral artery was used to continue PCPS support because of fasciotomy.

Figure 3. A: Comparison of the administered epinephrine dose between the 2 groups. B: Comparison of the administered norepinephrine dose between the 2 groups.

Figure 4. **A:** Comparison of the administered dopamine dose between the 2 groups. **B:** Comparison of the administered dobutamine dose between the 2 groups.

Table III. Results of Multivariate Regression Analysis

(Prior to PCPS induction)	Odds ratio	95% CI	P
Cardiac arrest	2.00	1.37-2.92	0.0052*
Use of CHDF	1.10	0.69-1.73	0.7074
APACHE II score	1.01	0.99-1.03	0.1916
Serum lactate level	1.01	0.99-1.03	0.3000
Administration of epinephrine	1.19	0.85-1.66	0.3432

DISCUSSION

Recent developments in medical engineering have resulted in innovations that have transformed PCPS into a compact, battery-powered, portable heart-lung machine that can be implemented rapidly in any area of the hospital using thin-walled cannulae inserted via the femoral vessels.⁷⁾ Because PCPS is a portable and powerful resuscitative tool, it has been effectively used for the treatment of cardiac failure in various situations such as postcardiotomy low output syndrome,^{6,8)} prolonged cardiopulmonary resuscitation,⁹⁾ and acute myocardial infarction.¹⁰⁾ Additionally, PCPS has been used prophylactically in high-risk coronary patients needing percutaneous stent revascularization.¹¹⁾ However, there are limitations with respect to whether PCPS can promote the recovery of left ven-

tricular function in the presence of seriously damaged myocardium. Some investigators have reported that the use of PCPS for cardiac arrest during coronary intervention in the catheterization laboratory and for postoperative low output syndrome (LOS) demonstrated a late survival rate ranging between 57-64%¹²⁻¹⁴⁾ and 56-66.7%,⁸⁾ respectively.

In this report, the background, characteristics, and prognosis of patients who had PCPS for the treatment of severe cardiac failure due to various causes, including postcardiac surgery, pulmonary thrombosis, acute myocardial infarction, acute myocarditis, and others were analyzed in order to clarify the effectiveness of PCPS. As a result, the rate of cardiac arrest prior to the start of PCPS and CHDF use were significantly ($P < 0.05$) lower in group A than in group B. Significant differences ($P < 0.05$) were found in the PCPS flow, APACHE II scores, serum lactate levels, and catecholamine dose from the start of PCPS to 72 hours after the start of PCPS between the 2 groups. In group A, the PCPS flow finally decreased and urine output increased gradually within 72 hours after starting PCPS. In addition, serum lactate levels decreased gradually, and the doses of catecholamine were also tapered. By contrast, none of these improvements were found in group B. Taking these results into consideration, it might be difficult to discontinue PCPS for patients if the APACHE II score and serum lactate levels do not decrease and the dose of catecholamine is not tapered. In general, the dose of catecholamine is usually tapered after PCPS induction, and is increased again when PCPS is terminated to maintain the hemodynamics, if necessary. If a high dose of catecholamine is required to maintain hemodynamics during PCPS use, it may be a sign that PCPS cannot be terminated.

There were significant differences ($P < 0.05$) between the 2 groups in the APACHE II scores and the epinephrine dose given at the start of PCPS use. One reason for these findings may have been a delay in the start of PCPS. PCPS was initially used to save the life of severe cardiac failure patients who required an extreme dose of catecholamine and in whom IABP was not sufficient to maintain the patient's circulation. PCPS should be started prior to increasing the catecholamine dose for preventing MOF development.

Multivariate logistic regression showed that cardiac arrest prior to deployment of PCPS was a significant predictor of patients who would require PCPS for the treatment of severe cardiac failure. As mentioned above, the interval between cardiac arrest and initiation of PCPS could not be evaluated in this study because these data were unclear in almost all patients. The evaluation of this interval should be the goal of a future study.

In conclusion, PCPS was relatively effective for the treatment of severe cardiac failure due to various causes. Patients with cardiac arrest prior to initiation of PCPS had a poor prognosis. In addition, PCPS could not be discontinued when

patients had high APACHE II scores and required high doses of catecholamine at the start of PCPS use, and a high APACHE II score, high serum lactate level, and high dose of catecholamine were maintained in spite of PCPS use. It is important to establish criteria for the deployment and discontinuation of PCPS and obtaining satisfactory results. The results of this study may help to establish those criteria for patients with severe cardiac failure.

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