原　著

Percutaneous Cardiopulmonary Support in the Last Decade

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Abstract

Percutaneous cardiopulmonary bypass support (PCPS) is a therapeutic option for patients with circulatory collapse. This study reviews clinical course and outcome of 19 patients treated with PCPS in the last decade at Hokkaido University Hospital. Patients included 13 males and 6 female with a mean age of 61.3 ± 2.9 years. The underlying diseases were perioperative circulatory collapse or low cardiac output syndrome (LOS) in 15 (cardiotomy group; 9 undergoing surgery for ischemic heart disease (IHD) and 6 for valvular heart disease), pulmonary emboli in 3, and dilative cardiomyopathy (DCM) in 1 patient. Thirteen of 19 patients (68.4%) were weaned from PCPS and 10 (52.6%) patients achieved hospital discharge. Rates of weaning from PCPS and hospital discharge in each underlying disease were 11/15 and 8/15 in cardiotomy group, 2/3 and 2/3 in pulmonary embolism, 0/1 and 0/1 in DCM, respectively. In cardiotomy group, all survivors showed remarkable improvement of hemodynamic state within 48 hours after PCPS and were weaned from PCPS (mean PCPS running time: 23.4 ± 4.7 hrs). In contrast, non-survivors (mean PCPS running time: 73.8 ± 8.0 hrs) showed no improvement within 48 hours and developed major complications such as cerebral damage or multiple organ dysfunction syndrome. We conclude that there is few possibility of weaning from PCPS in cardiotomy patients who cannot show any signs of hemodynamic recovery within 48 hours after the institution of PCPS. The limited use of PCPS within 48 hours may be applicable for post-cardiotomy patients. For patients with massive pulmonary emboli, PCPS may be beneficial in resuscitating patients with circulatory collapse and may be used as a bridge to pulmonary embolectomy.

Key Word : Circulatory support, Percutaneous cardiopulmonary bypass support (PCPS), Low cardiac output syndrome (LOS), Emergency extracorporeal circulation

INTRODUCTION

The technique for percutaneous cardiopulmonary bypass was first described by Phillips et al[1] and subsequently, remarkable advances in catheters, bypass circuit, and membrane oxygenators have allowed a wide acceptance of this approach to emergency circulatory support[2]. Currently, percutaneous cardiopulmonary bypass support (PCPS) is an established technique for maintaining the cardiac and pulmonary functions when the patient's cardiopulmonary status is failing.

The clinical application of PCPS includes an elective circulatory support during high-risk coronary interventions[3,4], resuscitative use for patients with cardiogenic shock mainly due to myocardial infarction, myocarditis, pulmonary embolism, cardiopulmonary arrest (CPA) for any reason in the emergency room, and a postcardiotomy low cardiac output syndrome (LOS)[5]. Results of the elective use for

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high-risk coronary interventions are favorable, but the reported outcomes of the emergency use of PCPS have been unsatisfactory in several series. This report reviews clinical course and outcome of 19 patients treated with PCPS in the last decade at Hokkaido University Hospital.

Patients and Methods

Nineteen adult patients treated with PCPS between April 1991 and March 2000 at Hokkaido University Hospital were retrospectively reviewed. All patients registered in this study were adult Japanese and consisted of 13 male and 6 female patients aged 37 to 74 (mean 61.3 ± 2.6) years. Underlying diseases or conditions in need of PCPS were perioperative circulatory collapse or LOS in 15 (cardiotomy group; 9 ischemic heart disease (IHD) and 6 valvular heart disease), massive pulmonary emboli in 3, and acute deterioration of dilative cardiomyopathy (DCM) in 1 patient. Perioperative circulatory collapse or LOS was

the most common reason, including 2 cases of preoperative circulatory collapse due to tachyarrhythmias and 13 cases of postoperative LOS. All these 15 patients underwent intraaortic balloon pump (IABP) in association with PCPS. The overview of patients profile in the cardiotomy group is summarized in Table 1. A solitary CABG (2 to 6 vessels) was undertaken for 7 patients with IHD. CABG and concomitant vascular surgery were performed on 2 patients (replacement of the aortic arch in 1, femoropopliteal bypass in 1). Six patients with valvular disease underwent AVR+MVR (n=1), AVR (n=2), MVR (n=1), Bentall operation (n=1) and Ross operation (n=1), respectively.

The PCPS systems employed in our institute were the Biomedicus® CARMEDA system (Medtronic Cardiopulmonary Division, Anaheim, CA) for the first 4 cases and the Capiox® EMERSAVE system (Terumo Inc., Tokyo, Japan) for 15 recent cases. In both systems, large-bore cannulas (15F arterial, 21F ve

Table 1   Summary of patients' profile and outcomes in cardiotomy group.

#	Age	Gender	Diagnosis	Procedure	PCPS introduction	Causes for the PCPS use	PCPS running time (hr)	Weaning from PCPS	Discharged from hospital	Complications
1	50	M	MR/AR/TR	DVR+TAP	post	PMI, LOS	82.4	N	N	Edema(++), preload↓, MODS
2	65	M	EAP	re-CABG(3)	pre	CA spasm, shock	3.0	Y	Y	
3	56	M	UAP	CABG(3)	post	PMI, LOS	20.0	Y	Y	
4	74	M	UAP	CABG(6)	post	LOS	41.7	Y	N	Cerebal hemorrhage
5	71	M	OMI/UAP	CABG(3)	post	PMI, LOS	110.5	N	N	Edema(++), preload↓, MODS
6	53	M	EAP	CABG(2)	pre	Arrhythmia, shock	28.0	Y	Y	
7	47	F	AR	AVR	post	CA spasm, LOS	18.0	Y	Y	
8	37	M	IE,AR	Ross	post	LOS	60.0	N	N	
9	55	M	OMI/AP/VT	CABG(2)	post	Arrhythmia	33.0	Y	Y	
10	73	M	EAP/ASO	CABG(1)+ F-P bypass	post	PMI, LOS	68.0	Y	N	MODS
11	73	F	MS	MVR	post	LOS	76.0	Y	N	MODS
12	66	M	OMI	CABG(2)	post	CA spasm, LOS	39.0	Y	Y	
13	59	M	AR/AAE	Bentall	post	CA spasm, LOS	38.0	Y	Y	MODS
14	70	M	AS	AVR+ root replacement	post	LOS	78.0	N	N	
15	70	F	EAP/TAA	CABG(1)+ Arch replacement	post	CA spasm, LOS	8.0	Y	Y	MODS

MR = mitral regurgitation, AR = aortic regurgitation, TR = tricuspid regurgitation, Ms = mitral stenosis, ASO = arteriosclerosis obliterans, MSR = mitral stenosis and regurgitation, AAE = annuloaortic ectasia, AS = aortic stenosis, TAA = thoracic aortic aortic aneurysm, DVR = double valve replacement, TAP = tricuspid annuloplasty, PMI = perioperative myocardial infarction, LOS = low cardiac output syndrome, MODS = multiple organ dysfunction syndrome, EAP = effort angina pectoris, CABG = coronary artery bypass grafting, F-P = femoro-popliteal, CA = coronary artery, UAP = unstable angina pectoris, OMI = old myocardion, MVR = mitral valve replacement, AVR = aortic valve replacement, IE = infective endocarditis, Ross = Ross procedure, VT = ventricular tachycardia, AP = angina pectoris, post = postoperatively, pre = preoperatively, Y = yes, N = no

nous) were inserted percutaneously by a routine Seldinger procedure. The 15F arterial cannula was positioned in the distal abdominal aorta or common iliac artery, and the 21F venous cannula was positioned in the right atrium. Both systems used a centrifugal vortex pump and a membrane oxygenator. The heparin-coated cannulas and bypass circuits have been employed for 17 patients since 1993, while the heparin-coated membrane oxygenator has been utilized for 14 patients since 1995. Initial infused dose of heparin for systemic anticoagulation was 3 mg/kg before 1993 and activated clotting time (ACT) was maintained at 300 seconds or longer. Since the introduction of the heparin-coated cannulas and bypass circuits in 1993, heparin dosage has been reduced to 1 mg/kg and ACT was maintained at 150-200 seconds. The systemic blood pressure during PCPS operation was regulated to 100-120 mmHg by the PCPS flow and with minimum inotropic supports. The EMERSAVE system, which was employed for the recent 15 cases, consists of a heparin-coated membrane oxygenator pre-connected with bypass circuits and a cone for the centrifugal pump, all in one package. This preassembled system is beneficial for the emergency case because of its rapid and fully automatic priming function[6].

The following variables were compared in the cardiotomy group between survivors and non-survivors: preoperative patient profiles, primary cardiac disease, intraoperative factors related to the operative procedures, maximum serum creatinine phosphokinase (CK) and CK-MB isozyme, postoperative hemodynamic variables (CI, PCPS flow, LVSWI, etc.), postoperative serum creatinine and urinary output. In other 4 patients (3 pulmonary emboli and 1 DCM), the clinical course is briefly summarized.

Statistical Analysis (in the cardiotomy group) : All continuous variables are presented as the mean± standard error (SEM): All data were analyzed by the use of Student's t-test or the chi-square test. Differences were considered significant at p<0.05.

RESULTS

Rates of weaning from PCPS and hospital discharge in each underlying disease were 11/15 and 8/15 in cardiotomy group, 2/3 and 2/3 in pulmonary embolism, 0/1 and 0/1 in DCM, respectively.

Cardiotomy group. In the cardiotomy group, 11 of 15 patients (73.3%) were weaned from PCPS and 8 patients (53.3%) reached hospital discharge. Three patients who were weaned from PCPS died of cerebral hemorrhage (n=1) and multiple organ dysfunction syndrome (MODS) (n=2). Rates of weaning from PCPS were relatively higher in patients with IHD (8 of 9; 88.9%) than in those with valvular diseases (3 of 6; 50.0%) but did not show any statistical significance (p=0.143). Survival rate was also relatively better in patients with IHD (6 of 9; 66.7%) than in those with valvular disease (2 of 6; 33.3%) but was not significantly different (p=0.231). In the comparison of demographic data and perioperative variables, no significant differences were noted between the survivors and non-survivors in the cardiotomy group except for the PCPS running time (23.4±4.7 vs 73.8 ±8.0 hrs; p<0.001) (Table 2).

Fig 1 shows the change of cardiac index according to the time course in survivors and non-survivors. Cardiac index in survivors improved within 48 hours after PCPS. In contrast, cardiac index in non-survivors showed no improvement during this period. The same trend was noted in the left ventricular stroke work index (LVSWI). Fig 2 shows a comparison of PCPS flow after the start of PCPS between survivors and non-survivors. In response to the recovery of cardiac function, PCPS flow could be decreased in 24 hours in all survivors. However, non-survivors required a full PCPS flow due to the lack of recovery of cardiac function. In the majority of non-survivors, bypass flow could not be maintained in the later period probably due to the massive capillary leakage.

In summary, remarkable improvement in hemodynamic variables was oftained in all survivors within 48 hours after PCPS. In contrast, non-survivors showed no improvement during this period and developed major complications such as cerebral dam-

Table 2 Comparisons of perioperative factors between survivors and non-survivors in cardiotomy group.

Factor	Survivors	Non-survivors	p value
Age	58.9 ± 2.7	64.0 ± 5.5	0.399
Gender (M/F)	6/2	6/1	0.554
AXC time (m)	156.4 ± 39.1	191.0 ± 31.3	0.515
CPB time (m)	348.0 ± 47.1	452.0 ± 92.5	0.300
IHD/VD	6/2	3/4	0.231
PCPS time (h)	23.4 ± 4.7	73.8 ± 8.0	<0.001**
Max CK (IU/l)	1690 ± 555	3075 ± 1473	0.367
CK-MB (IU/l)	59.2 ± 15.9	137.7 ± 60.4	0.131

AXC = aortic crossclamping, CPB = cardiopulmonary bypass, IHD = ischemic heart disease, VD = valvular heart disease,
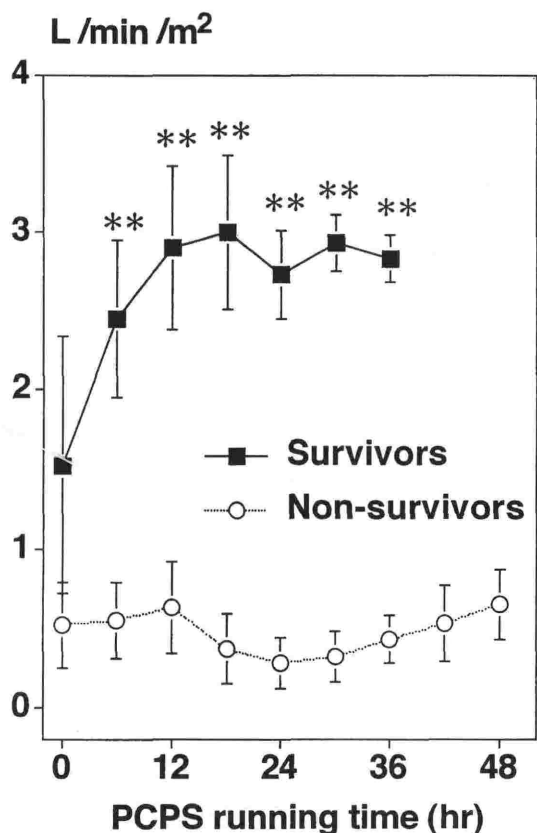CK = Creatinine phosphokinase

Fig 1. A comparison of the cardiac index after the institution of PCPS between survivors and non-survivors. *p<0.05,**p<0.01 vs non-survivors.
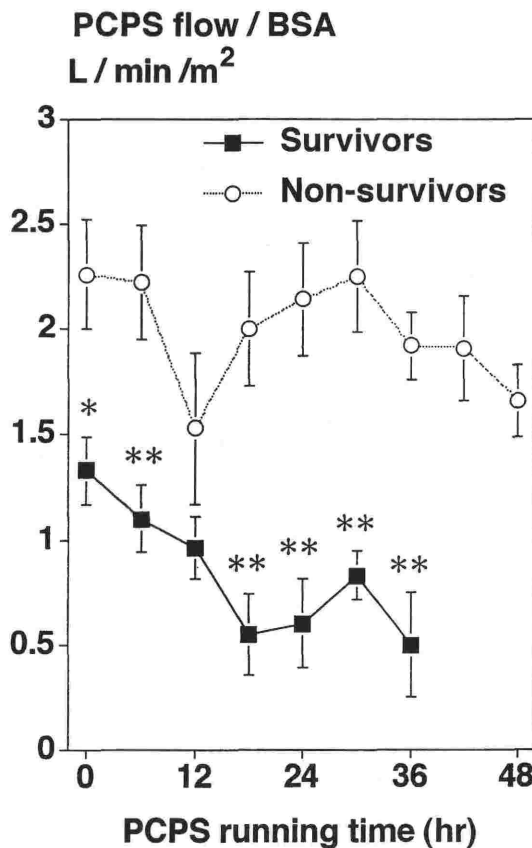

Fig 2. A comparison of the PCPS flow / body surface area (BSA) after PCPS between survivors and non-survivors. *p<0.05,**p<0.01 vs non-survivors.

age or multiple organ dysfunction syndrome (MODS).

PCPS for pulmonary emboli (n=3) and for DCM (n=1). Three patients with pulmonary emboli and 1 patient with acute deterioration of DCM have been

treated with PCPS during the study period. Unfortunately, 1 of 3 patients with pulmonary emboli and the patient with DCM could not survive. Two of 3 patients (66.7%) with pulmonary embolism were

weaned from PCPS and achieved hospital discharge. One of survivors was a female patient aged 72 years, who developed pulmonary emboli after cerebral infarction. The mai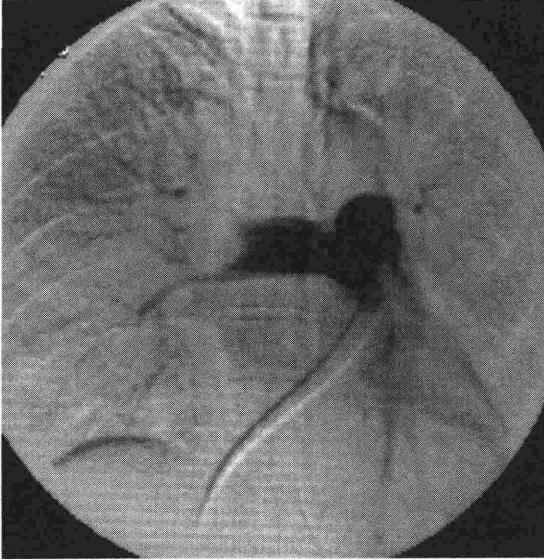n symptoms at onset were dyspnea, cyanosis, and hypoxia. Pulmonary angiogram revealed the massive emboli in the right main pulmonary artery (Fig 3). PCPS was immediately initiated to maintain systemic oxygenation and circulation. Afterwards the patient underwent pulmonary embolectomy and IVC filter insertion. She survived the operation and postoperative course was uneventful. Another survivor was a female patient aged 64, who developed pulmonary emboli after the hip joint replacement. The main symptom at onset was shock presenting a circulatory collapse. Pulmonary angiogram revealed the multiple emboli in both side of the pulmonary artery (Fig 4a). PCPS was immediately initiated to maintain systemic oxygenation and circulation. The patient also underwent pulmonary embolectomy (Fig 4b) and IVC filter insertion. She survived the operation and postoperative course was uneventful. In both cases, PCPS was successfully used as a bridge to the emergency pulmonary embolectomy.

Discussion

PCPS has been widely accepted as a therapeutic modality for temporary mechanical support[5]. This system is beneficial for maintaining hemodynamic status and visceral perfusion during circulatory col-

Fig 3. **Pulmonary angiogram showing the massive emboli in the right main pulmonary artery in a female patient aged 72.**

a
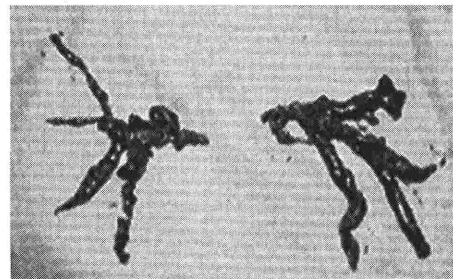
b

Fig 4. **Pulmonary angiogram showing the multiple emboli in both side of the pulmonary artery (4a) and extirpated emboli by surgical embolectomy (4b) in a female patient aged 64.**

lapse and for reducing the right ventricular preload. Although this system provides benefits to patients in a state refractory to standard cardiopulmonary resuscitation, the indication of PCPS has not reached a worldwide acceptance, especially for post-cardiotomy LOS[7]. Moreover, the criteria of institution of ventricular assist device (VAD) have not been determined in the case when PCPS is ineffective. Other problems of PCPS include hemorrhagic complications due to the use of anticoagulant and a short life span of the membrane oxygenator. Since the development of the heparin-coated circuit and the heparin-bonded membrane oxygenator, the required dose of anticoagulant for PCPS has been reduced[8]. However, the short life span of the membrane oxygenator remains to be solved because current PCPS systems usually need to be replaced every 48 to 72 hours due to serum leakage. The non-porous type membrane oxygenator (silicone membrane) can be used for the longer period without serum leakage, but may enhance hemorrhagic complications because current non-porous type is not heparin-bonded and thus requires full dose of anticoagulant.

Regarding clinical results of PCPS, its elective use for patients undergoing high-risk coronary intervention has demonstrated acceptable results, with the late survival rate ranging between 57-64% according to reports by Shawl[9,10], Mooney[5], and other investigators. However, the clinical use for post-cardiotomy LOS has been reported unsatisfactory, with the survival rate ranging between 4-30%[4,11]. Rates of recovery in our series were relatively higher than the survival rate previously reported, especially in patients undergoing coronary surgery. Hemodynamic variables in those patients weaned from PCPS showed remarkable improvement within 48 hours of the introduction of PCPS. In general, PCPS provides the excellent hemodynamic support when the patient's cardiopulmonary status is failing. However, there are some limitations as to whether PCPS promotes the recovery of LV function in the presence of seriously damaged myocardium. In the experimental model, PCPS can effectively support the failing myocardium, but it cannot augment coronary blood flow, and

substantial regional myocardial necrosis still occurs[12]. Further, PCPS may augment the left ventricular afterload unless the left atrium or ventricle is vented. It is speculated that the mechanism responsible for post-cardiotomy LOS in our series may be involved with a temporary, reversible deterioration of cardiac functions related to myocardial stunning, when considering that PCPS itself is less likely to promote the recovery of LV functions. In such cases, stunned myocardium may reach restoration during the circulatory support with PCPS.

Scholz et al emphasized the need for active left-ventricular decompression during PCPS running[13]. According to the report by Bavaria et al, the combination of PCPS and IABP has important advantages over PCPS alone in postischemic dilated, poorly contracting hearts[14]. Lazar et al also reported that the optimal salvage of ischemic myocardium was achieved by the addition of IABP support to PCPS[15]. For optimal clinical results, an adequate counterpulsation or decompression of the left atrium or ventriculum should be required during PCPS operation, which were undertaken for all 15 patients in cardiotomy group. Concomitant use of IABP may have contributed to the recovery of cardiac functions in our series.

The main cause of death in the cardiotomy group was MODS. In the majority of these cases, the bypass flow could not be maintained in the later period unless massive volume loading is performed. It remains unsettled why the loss of circulation volume occurred frequently 48 hours after PCPS. It is speculated that uncontrollable infection or inflammatory response may lead to the massive capillary leakage through the production of cytokines or other humoral mediators, but this remains unproved. Probably, institution of VAD should be considered once if cardiac function shows no improvement within 48 hours after the institution of PCPS. Further investigation is required to evaluate mechanisms that account for the loss of circulation volume in the later period of PCPS and to find determinants of PCPS running period.

Since the number of patients with pulmonary emboli is small in our series, we cannot show any trend or proof to demonstrate the usefulness of PCPS

in the treatment of pulmonary embolism. However, PCPS was successfully used as a bridge to the emergency pulmonary embolectomy in 2 of 3 patients. For patients with massive pulmonary emboli leading to circulatory collapse, PCPS is beneficial in resuscitating these patients and may be used as a bridge to pulmonary embolectomy.

In conclusion, hemodynamic variables in all survivors of the cardiotomy group showed remarkable improvement within 48 hours after the institution of PCPS. There is few possibility of weaning from PCPS in cardiotomy patients who cannot show any signs of hemodynamic recovery within 48 hours after the institution of PCPS. The limited use of PCPS within 48 hours may be applicable for post-cardiotomy patients. For patients with massive pulmonary emboli, PCPS is beneficial in resuscitating patients with circulatory collapse and may be used as a bridge to pulmonary embolectomy.

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