

소아연령의 개심술후 시행한, 심장 혹은 심장-폐 순환보조장치의 임상적 고찰 (Royal Children's Hospital, Australia의 경험)

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=Abstract=

Postcardiotomy Heart or Heart/Lung Assist Experiences in Children

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From April 1989 to December 1993, total 39 patients who were unable to be weaned off CPB or expected fatal immediate-postoperatively, were treated with ventricular assist device(VAD) or extracorporeal membrane oxygenator(ECMO) at the Royal Children's Hospital, Melbourne. Ages ranged from 3 days to 19.4 years old and body weights from 2.0 kg to 70 kg. Twenty-seven (69.2%) of 39 patients were weaned to be decannulated successfully and sixteen (41.0%) survived to hospital discharge and late survival rate was twelve (30.8%) of 39 patients. The total follow-up period was 4 to 56 months (32.92 ± 20.77 months) and most of the late survivals showed good myocardial recovery state. From the viewpoint of the assist modality, 29 patients were treated with VAD and among them, 23 were weaned from assist successfully, but among the 8 ECMO patients, only 3 could be weaned, and both modalities were performed to the 2 patients with one weaned. The total duration of assist was from 8 to 428 hours and there was a significant difference between hospital discharged group and hospital death group, which were 83.13 ± 31.29 hours vs 147.52 ± 112.03 hours ($P=0.032$). Conclusively, at the critical postcardiotomy situation of the paediatric patients including various congenital complex diseases and procedures, we can choose this VAD or ECMO treatment strategy as the reasonable life saving way except transplantation.

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Key words : 1. Heart assist device
2. Extracorporeal membrane oxygenation
3. Heart surgery, Pediatric

INTRODUCTION

A variety of life supporting devices and techniques have been used for the failing heart after cardiac operation and

nowadays the technique of LVAD has been considered as essential requisites for the adult cases especially coronary surgery¹⁻⁵⁾. Moreover, in the congenital cases, the reports of postcardiotomy support experience - mainly by using

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Table 1. Age distribution with survival data.

Age	No.	weaned	discharge	late survival
~1month	8	3	2	2
2~3months	11	6	6	3
4~6months	2	2	1	1
7~12months	2	2	1	1
1yr~5yrs	9	8	4	3
>6yrs	7	6	2	2

Table 2. B.Wt distribution with survival data.

Age	No.	weaned	discharge	late survival
<5kg	17	7	6	3
5~10kg	10	10	6	5
>10kg	12	10	4	4

the technique of ECMO—were increasing^{6, 7)}. We had reported the early experiences of 12 LVAD cases with 6 survivals in the paediatric cardiac operations⁸⁾. In this article, we described our treatment strategy for the failing heart after congenital cardiac operations and clinical results about 39 patients who had needed persistent circulatory or circulatory/respiratory support after various complicated cardiac operations.

PATIENTS AND METHODS

Between April 1989 and December 1993, 39 patients were treated with VAD or ECMO at critical state after open heart surgery. With the medical records, we analysed the survival rate according to the age, body weight, assist mode, indication of assist and diagnosis with surgical procedures, and the comparison of the hospital survival and non-survival group for the age, body weight, CPB time, ischaemic time and duration of assist, was done using the t-test with $P < 0.05$ significance, and also assessed the actuarial survival curve of all the patients. The patient's age were from 3 days to 19.4 years (39.82 ± 65.91 months) and body weight were 2.0 to 70 kg (14.58 ± 18.31 kg) (Table 1, 2).

By indication, the 29 patients were unable to come off CPB after open heart surgery even if adequate medication,

Table 3. Indication for Support.

	No.	weaned	discharge	late survival
Unweanable from CPB	29	21	12	8
Cardiac arrest in ICU	6	3	2	2
Deterioration in ICU	4	3	2	2
Total	39	27	16	12

Abbr) CPB: Cardiopulmonary bypass
 ICU: Intensive care unit

and the other 10 patients were progressively deteriorating (n=4) or cardiac arrest with or without CPR (n=6) in ICU after operation (Table 3).

The original diagnosis and operative procedures included various complex congenital heart anomalies and complicated procedures.

Shone's complex patients had the stenotic lesion at the left heart (usually mitral valve anomaly, LVOTO, aortic stenosis and arch anomaly etc.), so expected perioperative LV myocardial dysfunction (Table 4).

The decision making of VAD or ECMO was done at the critical stage with preference to the VAD after considering the haemodynamics (LAP, RAP), the extent of the surgical correction, pulmonary (oxygenation) state, or sometimes intra or postoperative echocardiographic evaluation.

29 patients were supported by VAD, 8 patients by ECMO, and 2 patients were supported by both modes (Table 5).

The procedures of LVAD was described precisely at the former report⁸⁾. When we applied ECMO, we added the oxygenator, heat exchanger and hemofilter to the circuit and maintained the ACT level more higher than VAD. All the patients were cannulated through the original sternal wound and usually used aortic cannulae with former one (Argyle aortic cannulae) and venous cannula with Rygg-Kyusgaard right angle atrial cannula through the junction of right upper pulmonary vein and left atrium for LVAD or through the right atrial appendage for ECMO or for the univentricular assist devise in the case of univentricular palliative operation.

The cannulae were exited through the sternotomy wound or inter or subcostal separate incision and the sternal wound was frequently closed by only skin layer or Goretex

Table 4. Operative diagnosis/procedure with survival data.

	No.	weaned	discharge	late survival
ALCAS	3	3	3	3
TGA: switch operation	3(1)*(1)**	1	1	1
T-B+arch hypoplasia: switch+arch repair	1	1	1	1
HLHS: Norwood I.	4	2	1	1
Transplantation	4(1)*	3	1	1
Bridge on VAD	1(1)**	Bridge	0	0
Shones Cplx varieties: correction	9(1)*	8	4	1
CAVC with valve anomaly: correction	3(1)*	0	0	0
Bacterial endocarditis: valve opx.	3(1)*	3	3	2
cTGA+Ebstein: double switch with TVR	1	1	1	1
Truncus	1	0	0	0
DKS+APS	1	1	0	0
Arch repair+PAB	1(1)*	0	0	0
Conversion to switch	1	1	0	0
DORV: correction	1(1)*	1	1	1
UVH: Fontan	1(1)*	0	0	0
UVH: BCPS	1	1	0	0

(1)*: ECMO support, (1)**: Bi-mode support

Abbr) ALCAS: Anomalous origin of left coronary artery syndrome, TGA: Transposition of the Great Arteries, T-B: Taussing-Bing anomaly
CAVC: Common Atrio-Ventricular Cannal, C-TGA: Corrected TGA, DKS: Daymus-Kaye-Stansel, APS: Arteripulmonary Shunt
PAP: Pulmonary Artery Banding, UVH: Univentricular Heart, BCPS: Bidirectional Cavopulmonary Shunt, VAD: Vantricular assist device
TVR: Tricuspid valvular replacement, DORV: Double outlet of right ventricle

membrane closure. We used assist device with Biomedicus centrifugal pump and for ECMO, the AVECOR (formally Sci-med) oxygenator and AVECOR ECMO therm heat-exchanger (Fig. 1, 2).

After getting the full flow of the assist device (150 ml/kg/min for patients under 10kg body weights or 2.5l/min/m² of the body surface area for patients over 10kg body weights) and stable haemodynamic parameters (systemic arterial pressure, left atrial pressure, right atrial pressure, pulmonary artery pressure) with adequate oxygenation, the patients were moved to ICU.

In ICU, ventricular contractions and filling pressures were maintained for the adequately fully assisted states (usually left atrial pressure 3~5 mmHg, right atrial pressure < 10mmHg) with colloidal volume adjustment and inotropics (minimal dose) and vasodilator.

We keep the activated clotting time 130~140 seconds for VAD and 160~180 seconds for ECMO with continuous infusion of heparin and if needed, we give the patient platelets. After a period of full support (usually 1 or 2 days interval), we try to wean off the VAD or ECMO for the

Table 5. Assist modes with survival data.

	No.	weaned	discharge	late survival
VAD	29	23	14	10
ECMO	8	3	2	2
Mixed	2	1	0	0
Total	39	27	16	12

Abbr) VAD: Vantricular assist device
ECMO: Extracorporeal membrane oxygenator

evaluation of myocardial recovery by means of haemodynamic parameter (adequate systemic arterial pressure, left atrial pressure < 8~10 mmHg, right atrial pressure < 12~15 mmHg) and echocardiogram with volume challenge.

If the patient shows stable haemodynamic and clinical status on minimal flow for the circuit (200ml/min) for 1 or 2 hours, we decannulate and perform sternal closure in the operation room.

On ECMO, the ventilator was maintained low ventilator rate (5~15/min), reduced FiO₂ (0.21), minimum peak inspir-

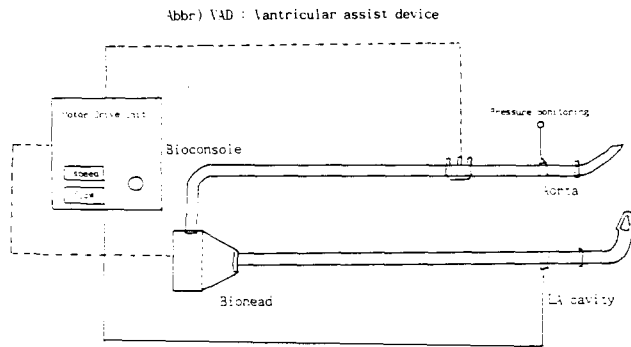


Fig. 1. VAD circuit in Royal Children Hospital.

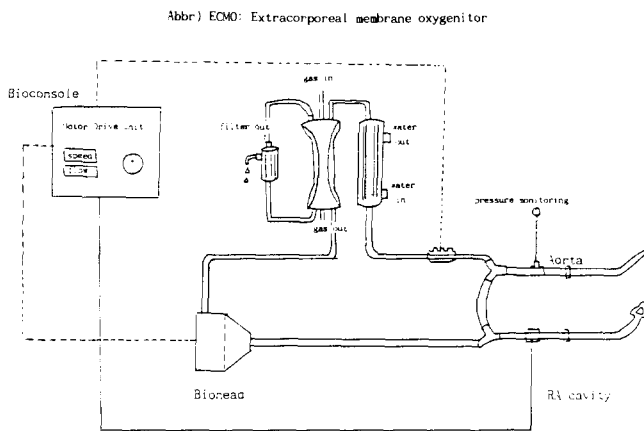


Fig. 2. ECMO circuit in Royal Children Hospital

atomy pressure to move the chest with positive end-expiratory pressure (5~15cmH₂O).

RESULTS

Survival Data

Total 39 patients were supported with VAD or ECMO after cardiac operation for the duration of 8 hours to 428 hours (mean = 121.10 ± 91.97hrs.) and 27 patients could be weaned off VAD or ECMO successfully (69.2%) and 16 patients among them could be discharged (41.0%). After 4 months to 56 months (mean = 32.92 ± 20.77 months) of follow-up, the 12 patients that survived (30.8%), mostly showed good recovery states.

There were 8 neonatal patients with only 3 weanable from assist (Table 1) and among the 17 patients who weig-

Table 6. Comparison between hospital discharged & undischarged group.

	Discharge (n=16)	Undischarged (n=23)	P.valve
Age (month)	29.32 ± 53.54	47.13 ± 74.90	0.420
Body weight(kg)	12.05 ± 14.35	16.35 ± 21.11	0.484
CPB time(min)	240.63 ± 156.72	245.70 ± 126.80	0.912
Ischemic time(min)	70.56 ± 39.62	93.35 ± 66.50	0.228
Duration of Assist(hour)	83.13 ± 31.29	147.52 ± 112.03	0.032

Abbr) CPB: Cardiopulmonary Bypass

hed less than 5kg body weights only 7 could be weanable from assist (Table 2).

All the patients were reassessed by the indication of assist, original diagnosis with operation, and the assist mode according to the number of weaning from assist, hospital discharged patients, and the late survival (Table 3, 4, 5).

Among the 29 patients who could not come off CPB after operation, 21 patients could be weaned from assist device successfully but only 12 were discharged from hospital (Table 3).

From the point of diagnosis and operation procedures, all 3 anomalous origin of left coronary artery syndrome who were repaired by intrapulmonary tunnel technique and needed LVAD for coming out of CPB were survived and showed excellently improved myocardial function on follow-up.

There were 5 transplantation patients with 3 weaned from assist device, and 21 patients who received total corrective repair for complex congenital disease with 13 weaned from assist device, and 7 patients done by palliative operation for the complex congenital disease with 4 weaned from VAD/ECMO. Three patients who were done by valvular operation because of acute bacterial endocarditis with valvular dysfunction were treated with VAD/ECMO and appropriate antibiotics with good results (Table 4).

We compared the hospital survival with non-survival group in Table 6, and there was nearly no difference of CPB time. However, the age and body weight of the patients and ischaemic time showed difference without statistical significance and the duration of assist time showed statistical difference between two groups. Using plotting survival with duration of assist, there was low survival chance after

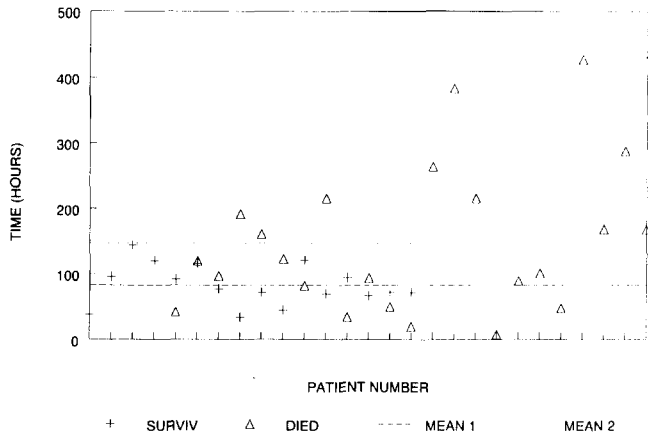


Fig. 3. Duration of Support (means=83 ± 31 vs 147 ± 112, p=.03)

5 days of assist (Fig. 3).

Complications

Fifteen patients needed re-exploration (sometimes several times) for bleeding control or evacuation of the haematoma from the pericardial space after commencement of VAD/ECMO. Definite sepsis developed in 10 patients and 4 patients died. There was some clinical suggestion of CNS thrombosis or haemorrhagic events during assist periods and one autopsy finding of cerebral infarct, but all the survivors showed no significant neurologic complication nor sequelae.

There were two cases of pump head failure during assist and they were changed without problem.

Cause of Death

Most of the 12 patients who were not able to come out of assist device, were considered not to have recovered from myocardial damage, or intolerable anatomic correction for survival. Among the 27 patients who could be weaned from assist device, 11 patients died in hospital because of sepsis (n=4), persistent marginal low cardiac output with multiple organ failure (n=3), sudden deterioration or cardiac arrest (n=3) after removal of VAD/ECMO. The 4 late deaths were due to sudden arrest (n=2), lung infection (n=1), and unknown cause (n=1).

Follow-up

The 12 late-survivals were followed up for the duration

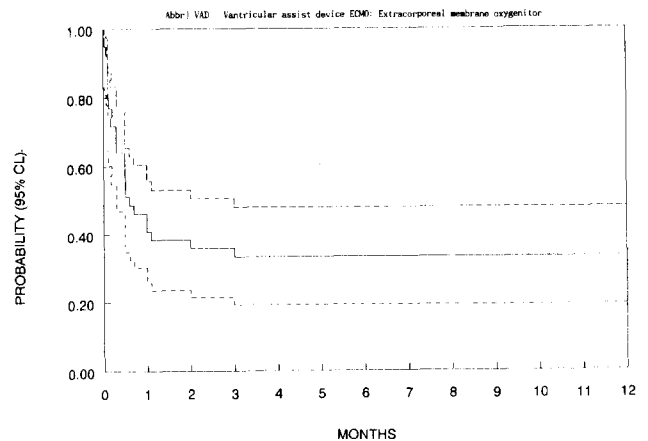


Fig. 4. Actuarial Survival Following Initiation of Vad or Ecmo

of 4-56 months (mean=39.92 ± 20.77 months). All the survivors showed excellent recovery of ventricular function and well growing state with completely corrected state or waiting for the next stage operation, except 2 patients who suffered from mild fluctuating symptoms and signs of heart failure due to original complexities of the diseases and procedures.

Discussion

Even though the rapid improvement of postcardiotomy circulatory support and clinical results, there are still some controversies, and one of them was about the pediatric cases^{6, 9, 10}. And as a matter of fact, many centers choose the ECMO as the first choice for the pediatric case for the reason that the frequent development of right heart dysfunction associated with pulmonary hypertension or combined left and right heart failure after operation^{6, 9-11}.

However we have tried to treat the pediatric postcardiotomy heart failure cases with our criteria of the choice for VAD or ECMO since 1989, and total 39 patients were needed VAD or ECMO after open heart surgery and among them VAD-alone cases were 29 (74.4%).

And considering the overall clinical results, the weaning success rate and hospital discharge rate were 69.2% and 41.0% respectively, it was nearly as same as the other centers of ECMO preference for the pediatric cases^{6, 7, 10, 11}.

The VAD has some advantages over ECMO; (1) the circuit is more simple, (2) the less heparine is needed, so that the bleeding complication is much less, (3) the oxygenator

is not needed, so that less hemolytic complication make the assist duration longer without blood trauma theoretically, ④ the decompression effect of the systemic ventricle is more definite.

So we choose the VAD as the first choice when we met the postcardiotomy failing heart except the cases that more severe right heart failure was expected or in the case of VAD alone with the results of poor oxygenation or low cardiac output due to right heart failure or poor pulmonary conditions.

During the VAD alone, we considered of right heart function, so we continued to give some dose of inotropics and volume treatment to keep the right atrial pressure and right ventricular function properly.

And our results showed that the case selection for the ECMO or VAD in the pediatric patients is needed as well.

The difference of weaning success rate of ECMO and VAD in our results (37.5% (3/8) v.s. 79.3% (23/29)) shows that biventricular failure could be the risk factor⁷⁾(Table 5).

The indications for mechanical support were mainly the cases(29/39) that couldn't be weaned from CPB after open heart surgery. Others were sudden cardiac arrest during the immediate postoperative course in 6 cases, and acutely deteriorated in 4 cases. When we want to apply the mechanical support for the postoperation failing heart, the adequacy of anatomic correction and the reversibility of myocardial dysfunction caused perioperatively, were to be considered together. The anomalous origin of left coronary artery syndrome was a good candidate for the LVAD after repair, so that all the cases were successfully weaned and showed excellent recovery^{13, 14)}.

The other indications of LVAD rather than ECMO could be based on the idea that the corrected heart needed left ventricular training in some meaning, for example, arterial switch operation for TGA¹⁵⁾, TAPVR with small LV, Shone's complex, double switch operation, conversion to switch...etc.

Other interesting results were the case of palliative operation that was shunt-dependent pulmonary blood flow with univentricular assist(UVAD); there were 4 cases of Norwood operations of hypoplastic left heart syndrome and two of them could be weaned from VAD and one patient survived to the next stage operation.

Other palliative cases were Damus-Kaye-Stansel procedure with aorto pulmonary shunt and Bidirectional cavopulmonary shunt with successful weaning from UVAD but no late survival.

Valvular disease and transplantation were also considered left ventricular dysfunction more frequently significant rather than right ventricle.

Other complete AV canals with right and left atrio-ventricular valve dysfunction, DORV with small RV and right ventriculotomy cases were thought to be needed right side assist also, so ECMO should be chosen rather than LVAD.

Although the age, body weight, CPB time, ischemic time could not show the statistical significant difference between hospital survival and non-survival group, among the 17 patients less than 5 kg body weights, only 7 were weaned from assist, but among the 22 over 10 kg body weights, 20 patients were weanable from assist (Table 2, 4).

The duration of assist for the hospital discharge group were significantly less than undischage group, that means if the myocardial function was recovered and could be weaned from assist within about 3 or 4 days, the survival rate was high, and if the assist was needed beyond that periods, the hospital survival chance was significantly low (Fig. 3)¹⁶⁾.

Conclusively, the salvage rate of postcardiotomy deteriorating heart in the pediatric patients were 36% of 1 year actuarial survival rate in the cases of nearly 100% death was expected without mechanical support at the intra-or postoperative critical states (Fig 4). And the pediatric patients could be also selected for the VAD or ECMO case by case.

References

1. Park SB, Liebler GA, Burkholder JA, et al. *Mechanical support of the failing heart*. Ann Thorac Surg 1986, 42:627-31
2. Pae WE. *Ventricular assist devices and total artificial heart: A combined registry experience*. Ann Thorac Surg 1993, 55:295-8
3. Soeter JR, Mamiya RT, Sprague AY, McNamara JJ. *Prolonged extracorporeal oxygenation for cardiorespiratory failure after tetralogy c correction*. J Thorac Cardiovasc Surg 1973, 66:214-8
4. Bartlett RH, Gazzaniga AB, Gupta KB, et al. *Prolonged extracorporeal cardiopulmonary support in man*. J Thorac Car-

diovasc Surg 1974, 68:918

5. Pae WE, Miller CA, Matthews Y, Pierce WS. *Ventricular assist devices for postcardiotomy cardiogenic shock. A combined registry experience.* J Thorac Cardiovasc Surg 1992, 104: 541-53
6. Spray TL. *Extracorporeal membrane oxygenation for pediatric cardiac support.* Cardiac Surgery: State of the Art Reviews. 1993, 7:177-88
7. Dalton HJ, Siewers RD, Fuhrman BP, et al. *Extracorporeal membrane oxygenation for cardiac rescue in children with severe myocardial dysfunction.* Crit Care Med 1993, 21:1020-8
8. Karl TR, Sano S, Horton S, Mee R BB. *Centrifugal pump left heart assist in pediatric cardiac operations. Indications, technique, and results.* J Thorac Cardiovasc Surg 1991, 102:624-30
9. Kanter KR, Pennington DG, Weber TR, et al. *Extracorporeal membrane oxygenation for postoperative cardiac support in children.* J Thorac Cardiovasc Surg 1987, 93:27-35
10. Pennington DG, Swartz MT, Swartz MT. *Circulatory support in infants and children.* Ann Thorac Surg 1993, 55:233-7
11. Meliones JN, Custer JR, Snedecor S, et al. *Extracorporeal life support for cardiac assist in Pediatric patients. Review of ELSO Registry Data.* Circulation 1991, 84(Suppl III) III-168-72
12. Nido PJ, Dalton HJ, Thompson AE, Siewers RD. *Extracorporeal membrane oxygenator rescue in children during cardiac arrest after cardiac surgery.* Circulation 1992, 86(Suppl II): II-300-4
13. Dua R, Smith JA, Wilkinson JL, et al. *Long-term follow up after two coronary repair of anomalous left coronary artery from the pulmonary artery.* J Card Surg 1993, 8:384-90
14. Raithel SC, Pennington DG, Boegner E, Fiore A, Weber TR. *Extracorporeal membrane oxygenation in children after cardiac surgery.* Circulation 1992, 86(Suppl II):II-305-10
15. Davis AM, Wilkinson JL, Karl TR, Mee R BB. *Transposition of the great arteries with intact ventricular septum: arterial switch repair in patients 21 days of age or older.* J Thorac Cardiovasc Surg 1993, 106:111-5
16. Rose DM, Colvin SB, Culliford At, et al. *Late functional and hemodynamic status of surviving patients following insertion of the left heart assist device.* J Thorac Cardiovasc Surg 1983, 86: 639-45

=국문초록=

개심술직 후 인공심폐기의 제거실패 등, 치명적으로 생명유지가 불안정한 상태의 환자들에 있어서, 심장 혹은 심폐보조장치에 의한 구명효과 및 소아 연령에서의 심실보조장치 혹은 심폐보조장치의 구분 사용에 대한 Royal Children's Hospital, Melbourne, Australia의 임상경험을 분석하였다.

1989년 4월부터 1993년 12월까지 총 39례의 소아환자에서, 개심술후 인공심폐기 제거실패나 수술 직후 중환자실에서 심폐정지 혹은 갑작스럽게 불안정해진 환자의 경우 심실보조장치(Ventricular assist device-VAD)나 심폐순환보조장치(Extracorporeal membrane oxygenator-ECMO)를 사용하였다.

환자의 연령은 생후 3일부터 19.4세 (평균 39.82 ± 65.91개월)였고, 체중은 2.0 kg 부터 70 kg (14.58 ± 18.31 kg)이었다.

총 39례중 27례 (69.2%)에서 성공적으로 보조장치의 제거가 가능했으며, 그중 16명 (41.0%)이 퇴원할 수 있었다.

총 추적기간은 4개월에서 56개월까지 (32.92 ± 20.77개월)였는데, 분석기간까지 생존례가 12례로 만기 생존률은 30.8%였으며, 생존례들은 대부분 양호한 심근회복 상태를 보였다.

전체 환자중 심실보조장치(VAD)만을 이용한 경우가 29례 (이중 23례가 보조장치 제거 성공)였으며, 심폐순환보조장치(ECMO)를 이용한 경우가 8례 (이중 3례만이 보조장치 제거 성공), 양쪽 보조장치를 다 이용해야 했던 경우가 2례 (1례만이 보조장치 제거 성공)였었다.

환자의 원래 질환은 대부분 선천성 복합 심기형이었으며, 그외 판막질환이나 심장이식례도 있었다. 총 보조시간은 8시간에서 428시간 이었는데 (121.10 ± 91.97시간), 병원에서 퇴원이 가능했던 생존군과 병원사망군을 비교해 볼때, 각각 83.13 ± 31.29시간 및 147.52 ± 112.03시간으로 통계적으로 유의한 차이를 보였다(p=0.032).