Venoarterial extracorporeal membrane oxygenation for treatment of cardiogenic shock: Clinical experiences in 45 adult patients

Farhad Bakhtiary, MD,^a Harald Keller,^b Selami Dogan, MD,^a Omer Dzemali, MD,^a Feyzan Oezaslan, MD,^a Dirk Meininger, MD, PhD,^c Hanns Ackermann, MD, PhD,^d Bernhard Zwissler, MD, PhD,^c Peter Kleine, MD, PhD,^a and Anton Moritz, MD, PhD^a

Objective: Venoarterial extracorporeal membrane oxygenation is an established treatment option in patients with cardiogenic shock. This report reviews our 3-year experience with this support system with respect to early and midterm outcome, as well as predictors of survival.

Methods: From January 2003 until November 2006, 45 (0.8%) of 5750 patients undergoing cardiac surgery procedures required the following: temporary extracorporeal membrane oxygenation support coronary artery bypass grafting, n = 20; implantation of a left ventricular assist device, n = 5; heart transplantation, n = 1; heart and lung transplantation, n = 1; coronary artery bypass grafting plus repair of postinfarction ventricular septal defect, n = 3; coronary artery bypass grafting plus mitral valve repair, n = 5; aortic valve replacement, n = 2; coronary artery bypass grafting plus aortic valve replacement, n = 3; and other procedures, n = 5. Extracorporeal membrane oxygenation implantation was performed through the femoral vessels or axillary artery or through the right atrium and ascending aorta. Additional intra-aortic balloon pumps were used in 30 patients.

Results: Average patient age was 60.1 ± 13.6 years. There were 35 male patients. Average duration of extracorporeal membrane oxygenation was 6.4 ± 4.5 days. Twenty-five patients could be successfully weaned from extracorporeal membrane oxygenation. The 30-day mortality was 53% (24/45 patients). The in-hospital mortality was 71% (32/45 patients). Thirteen (29%) patients could be successfully discharged. After a follow-up period of up to 3 years, 10 (22%) patients were still alive.

Conclusions: Extracorporeal membrane oxygenation offers sufficient cardiopulmonary support in adults with similar hospital and midterm survival rates to those of other mechanical support systems. Early indication, alternative peripheral cannulation techniques, and reduced anticoagulation to avoid perioperative bleeding could improve our results with increasing experience.

Since the first implantation by Hill and colleagues,¹ extracorporeal membrane oxygenation (ECMO) has been an established treatment option in adult patients with refractory cardiogenic shock,² providing prolonged but temporary cardiac and respiratory support. Refractory myocardial dysfunction before or

From the Departments of Thoracic and Cardiovascular Surgery,^a Perfusion and Cardio-technique,^b Anaesthesiology, Intensive Care Medicine, and Pain Therapy,^c and Biomedical Statistics,^d Johann Wolfgang Goethe University Hospital, Frankfurt/Main, Germany.

Received for publication Jan 31, 2007; revisions received May 13, 2007; accepted for publication Aug 9, 2007.

Address for reprints: Farhad Bakhtiary, MD, Department of Thoracic and Cardiovascular Surgery, Johann Wolfgang Goethe University, Theodor Stern Kai 7, 60590 Frankfurt am Main, Germany) (E-mail: farhad@bakhtiary.de).

J Thorac Cardiovasc Surg 2008;135:382-8
0022-5223/\$34.00

Copyright © 2008 by The American Association for Thoracic Surgery
doi:10.1016/j.jtcvs.2007.08.007

Abbreviations and Acronyms

CABG = coronary artery bypass grafting
ECMO = extracorporeal membrane oxygenation
IABP = intra-aortic balloon pump

during cardiac surgical procedures with development of severe cardiogenic shock is a rare but serious complication accompanied by an almost 100% mortality. In this small group of patients, ECMO might provide sufficient hemodynamic support to allow recovery from reversible myocardial injury.^{3,4}

Many studies have reported excellent results of ECMO in children,⁵ with outcome depending on the indication for ECMO. In adults, ECMO was reported to be less successful, but early use demonstrated favorable results compared with secondary implantation.^{6,7} Since 2002, we have used ECMO in our institution for patients who otherwise could not be weaned from extracorporeal circulation. The purpose of this study was to retrospectively review the early and midterm outcome of our patients and determine specific predictors of survival.

Materials and Methods

From January 2003 through November 2006, 45 of 5750 patients with refractory cardiogenic shock were placed on venoarterial ECMO by using heparin-coated circuits (Medtronic, Minneapolis, Minn). The criterion to use ECMO for cardiopulmonary support was the inability to treat cardiogenic shock with conventional methods of support, such as catecholamines or an intra-aortic balloon pump (IABP). The following cardiac surgical procedures were performed: coronary artery bypass grafting (CABG) for acute myocardial infarction and preoperative cardiogenic shock, $n = 20$; implantation of a left ventricular assist device, $n = 5$; heart transplantation, $n = 1$; heart and lung transplantation, $n = 1$; CABG plus repair of postinfarction ventricular septal defect, $n = 3$; CABG plus mitral valve repair, $n = 5$; aortic valve replacement (AVR), $n = 2$; CABG plus AVR, $n = 3$; and other procedures, $n = 5$.

ECMO Circuit

The ECMO circuit consisted of a closed, heparin surface-coated circuit of polyvinyl chloride tubing (Medtronic) and either a Biomedicus Biopump (Medtronic) or a Jostra-Maquet Rotaflow RF 32 (Jostra Medizintechnik, Hirrlingen, Germany), a centrifugal pump that propels blood through a hollow-fiber membrane oxygenator (Maxima P.R.F., Medtronic). Blood flow was monitored by using a Doppler flow probe placed on the arterial side of the circuit. Venoarterial ECMO was instituted by means of peripheral cannulation (common femoral artery and vein) in 29 (64%) patients, subclavian artery and femoral vein cannulation in 8 (18%) patients, and central cannulation (ascending aorta and right atrium) in 8 (18%) patients. Central cannulation was performed in patients, mainly in the early course of our experience. For better patient mobilization and avoidance of bleeding, possible thrombus forma-

tion at the arterial cannula, and infective complications in the presence of an open sternotomy we changed our strategy and switched to a femoral or subclavian cannulation. In 2 patients (1 receiving CABG and 1 receiving CABG plus mitral valve repair), retrograde femoral artery cannulation was converted to subclavian artery cannulation to achieve adequate ECMO support in regard to performing better upper body oxygen saturation.

To avoid limb ischemia observed in some early cases with peripheral cannulation, we optimized the distal limb perfusion by using an 8-mm Dacron T-graft (end-to-side anastomosis to the femoral or subclavian artery), which was tied on a 20F arterial cannula (Medtronic) to ascertain both central arterial blood flow and distal limb perfusion.

Initially, patients were heparinized as early as possible to achieve an activated clotting time of 160 to 180 seconds, but because we observed too many cases of diffuse bleeding complications, we began to antagonize heparin completely and maintain sufficient hemostasis to prevent further bleeding complications. Anticoagulation with heparin was started after chest drainage was less than 50 mL/h. The target partial thromboplastin time was between 50 and 60 seconds.

Multidisciplinary Management Strategy

All but 2 patients were supported with the intention to wean from ECMO (bridge to recovery). Intravenous inotropic doses were minimized or withdrawn to decrease myocardial oxygen demand and facilitate myocardial recovery, especially in patients with acute myocardial infarctions. IABP support was encouraged while patients received ECMO and was used in 30 of 45 patients. Atrial septostomy or ventricular venting was not used. Recovery was assessed daily by means of clinical, hemodynamic, and echocardiographic findings.

When recovery was unlikely, patients were evaluated for transplantation or permanent assist implantation. Candidacy for transplantation or left ventricular assist device implantation was made on a case-by-case basis. In all patients demonstrating recovery, weaning was performed, with slow reduction of ECMO flow over 48 hours. ECMO had to be withdrawn from some patients, with the knowledge that survival was unlikely and continued support was futile.

Pump flows were chosen to supply at least adequate total systemic circulatory support ($2.5 \text{ L} \cdot \text{min}^{-1} \cdot \text{m}^{-2}$) and to achieve a mixed venous oxygen saturation of more than 70%. Oxygen flow was gradually adjusted as necessary to meet the oxygen requirements of the patient. Pulmonary artery pressure and cardiac output were continuously monitored with a Swan-Ganz Catheter. Transesophageal echocardiography was performed multiple times in all patients while receiving ECMO to enable progressive assessment of myocardial recovery and provide useful information regarding myocardial contractility and ventricular filling during the weaning process.

General Patient Care

In all patients, sedation was morphine and midazolam based and was used to achieve patient comfort while enabling a daily neurologic assessment. Mechanical ventilation with biphasic positive airway pressure was continued throughout the ECMO period. ECMO was set at a tidal volume of 5 to 7 mL/kg, a rate of 8

TABLE 1. Preoperative patient characteristics

	Total	CABG	AVR	CABG + MVR	CABG + AVR	LVAD	CABG + VSD	HTX	Others*
No.	45	20	2	5	3	5	3	2	5
Age (y)	60.1 ± 13.6	60.5 ± 13	68.5 ± 7.8	65.8 ± 5.8	51.0 ± 18.0	57.0 ± 16.0	69.3 ± 1.5	45 ± 18.4	54.0 ± 18.4
Male sex	35 (78%)	15 (75%)	1 (50%)	4 (80%)	3 (100%)	4 (80%)	3 (100%)	1 (50%)	4 (80%)
Female sex	10 (22%)	5 (25%)	1 (50%)	1 (20%)	0 (0%)	1 (20%)	0 (0%)	1 (50%)	1 (20%)
Body mass index	26.7 ± 4.1	28.5 ± 4	23.5 ± 3.1	27.0 ± 2.8	23.5 ± 7.1	23.9 ± 3.5	26.4 ± 2.8	22.8 ± 2.2	26.0 ± 2.2
Diabetes	38 (84%)	19 (95%)	1 (50%)	4 (80%)	1 (33%)	4 (80%)	3 (100%)	2 (100%)	4 (80%)
PHT	37 (82%)	15 (75%)	2 (100%)	4 (80%)	1 (33%)	5 (100%)	3 (100%)	2 (100%)	5 (100%)
aHT	17 (38%)	9 (45%)	1 (50%)	1 (20%)	1 (33%)	3 (60%)	2 (67%)	1 (50%)	1 (20%)
Hyperlipidemia	31 (69%)	17 (85%)	0 (0%)	2 (40%)	1 (33%)	3 (60%)	3 (100%)	1 (50%)	3 (60%)
LVEF (%)	25.8 ± 10	24.6 ± 8.8	68.5 ± 7.8	27.0 ± 6.7	21.7 ± 2.9	18.0 ± 2.7	23.3 ± 2.9	22.6 ± 5.0	35.0 ± 7.0
Acute MI	32 (71%)	17 (85%)	0 (0%)	5 (100%)	3 (100%)	2 (40%)	3 (100%)	0 (0%)	2 (40%)
CPR (preoperative)	31 (69%)	12 (60%)	1 (50%)	2 (40%)	3 (100%)	4 (80%)	3 (100%)	1 (50%)	5 (100%)

CABG, Coronary artery bypass grafting; AVR, aortic valve replacement; MVR, mitral valve repair; LVAD, left ventricular assist device; VSD, ventricular septal defect; HTX, heart transplantation; PHT, pulmonary hypertension; aHT, arterial hypertension; LVEF, Left ventricular ejection fraction; MI, myocardial infarction; CPR, cardiopulmonary resuscitation. *Including double-valve replacement (n = 2), liver transplantation (n = 2), and type A aortic dissection (n = 1).

breaths/min, a positive end-expiratory pressure of 10 cm H₂O to prevent alveolar collapse, and a maximum ventilation pressure of 20 cm H₂O to avoid barotrauma. PCO₂ was kept within the normal range to prevent organ damage. Respirator settings were kept at parameters known to avoid additional lung injury to avoid development of pulmonary failure. Prone positioning was also used. ECMO flow was never reduced to less than 1 L/min until explanation to avoid any intrasystemic clotting. Enteral feeding was instituted in all patients on the first postoperative day and continued if tolerated.⁸ Antibiotics were used if infection was clinically suspected. Hyperglycemia was avoided by means of continuous infusion of insulin. Perfusion of the lower limbs was checked every 6 hours by means of physical examination, and 12-hour creatine kinase measurements were taken. All surviving patients were followed up after hospital discharge every 6 months in our outpatient department or by telephone to assess their clinical status and exercise capacity (100% complete follow-up).

Data Collection

Data collection was performed prospectively and focused on intraoperative and postoperative data, cannulation methods, duration of support, blood product use, use of hemofiltration, and use of IABP. Data were also obtained for 30-day mortality and in-hospital outcome.

Statistical Analysis

All statistical analyses were performed with the Statview program (Cary, NC). Categorical variables are expressed as percentages and were evaluated with χ^2 or Fisher exact tests. Continuous variables are expressed as means ± standard deviation and were evaluated by using the Student *t* test or the Kruskal–Wallis test. Logistic regression analysis was used to determine the predictors of survival. Long-term survival was calculated according to the Kaplan–Meier method.

Results

Demographics and pre-ECMO risk profiles of the 45 patients are summarized in Table 1. The patients were divided into subgroups with relation to their indication for cardiac surgery.

Table 2 demonstrates the intraoperative data of the different ECMO groups. The support system was used in the operating room in 30 (67%) patients and in the intensive care unit in 15 (33%) patients. ECMO implantation was successful in all cases.

Table 3 shows the outcome of ECMO support for the different groups. Mean duration of ECMO support was 6.4

TABLE 2. Intraoperative data

	Total	CABG	AVR	CABG + MVR	CABG + AVR	LVAD	CABG + VSD	HTX	Others*
No.	45	20	2	5	3	5	3	2	5
IABP	30 (67%)	15 (75%)	1 (50%)	4 (80%)	2 (67%)	2 (40%)	3 (100%)	2 (100%)	1 (20%)
Reoperation	5 (11%)	1 (5%)	1 (50%)	1 (20%)	0 (0%)	0 (0%)	1 (33%)	1 (50%)	0 (0%)
CPB time (min)	156.6 ± 66.1	131.8 ± 66.4	23.5 ± 3.1	193.8 ± 71.6	162.3 ± 52.6	144.3 ± 14.4	173.0 ± 46.0	224 ± 80	315 ± 66.4

CABG, Coronary artery bypass grafting; AVR, aortic valve replacement; MVR, mitral valve repair; LVAD, left ventricular assist device; VSD, ventricular septal defect; HTX, heart transplantation; IABP, intra-aortic balloon pump; CPB, cardiopulmonary bypass. *Including double-valve replacement (n = 2), liver transplantation (n = 2), and type A aortic dissection (n = 1).

TABLE 3. ECMO results

	Total	CABG	AVR	CABG + MVR	CABG + AVR	LVAD	CABG + VSD	HTX	Others*
No.	45	20	2	5	3	5	3	2	5
Duration of ECMO (d)	6.4 ± 4.5	6.8 ± 4.2	6.0 ± 2.8	4.3 ± 2.5	5.2 ± 7.8	8.0 ± 4.2	4.3 ± 2.9	6.2 ± 5.3	7.2 ± 5.2
Successful weaning	25 (56%)	12 (60%)	2 (100%)	1 (20%)	2 (67%)	5 (100%)	2 (67%)	1 (50%)	0 (0%)
Bridge to long-term assist device	5 (11%)	0 (0%)	0 (0%)	0 (0%)	0 (0%)	5 (100%)	0 (0%)	0 (0%)	0 (50%)
Heart transplantation	2 (4%)	0 (0%)	0 (0%)	0 (0%)	0 (0%)	0 (0%)	0 (0%)	2 (100%)	0 (50%)
Mechanical ventilation (d)	12.6 ± 10.3	11.6 ± 8.8	11.0 ± 1.4	16.7 ± 22.7	7.2 ± 8.6	24.0 ± 14.2	12.0 ± 6.9	11.5 ± 4.2	9.8 ± 6.2
ICU stay (d)	21.55 ± 20.8	21.1 ± 18.4	47.5 ± 3.5	17.0 ± 23.4	21.0 ± 28.5	24.0 ± 14.2	45.3 ± 1.4	54.5 ± 4.5	8.8 ± 6.3
Post-ECMO hospital stay (d)	25.6 ± 19.2	18.2 ± 15.8	30.5 ± 14.8	33.2 ± 2.9	34.5 ± 13.4	34.0 ± 1.7	59.5 ± 2.1	59.3 ± 30.3	0.3 ± 0.8
30-d Mortality	24 (53%)	10 (50%)	1 (50%)	4 (80%)	3 (100%)	2 (40%)	1 (33%)	1 (50%)	2 (40%)
Discharged from hospital	13 (67%)	6 (30%)	1 (50%)	0 (0%)	0 (0%)	3 (60%)	2 (67%)	1 (50%)	0 (0%)
In-hospital mortality	32 (71%)	14 (70%)	1 (50%)	5 (100%)	3 (100%)	2 (40%)	1 (33%)	1 (50%)	5 (100%)

CABG, Coronary artery bypass grafting; AVR, aortic valve replacement; MVR, mitral valve repair; LVAD, left ventricular assist device; VSD, ventricular septal defect; HTX, heart transplantation; ECMO, extracorporeal membrane oxygenation; ICU, intensive care unit. *Including double-valve replacement (n = 2), liver transplantation (n = 2), and type A aortic dissection (n = 1).

± 4.5 days; 25 (55%) patients were successfully weaned. Of the 25 patients with successful weaning from ECMO, 13 (52%) could be discharged from the hospital. IABP was used in 67% (30/45) of all patients and in 94% of the patients with acute myocardial infarctions.

Five patients were assessed to be suitable candidates for implantation of a long-term ventricular assist device. All of these patients received the Heart Mate II left ventricular assist device (Thoratec, Inc, Woburn, Mass). Two patients died in this group of multiorgan failure after successful weaning from ECMO. The remaining 3 patients could be discharged from the hospital. One patient was suitable for heart and 1 patient for

concomitant heart–lung transplantation. The patient undergoing heart–lung transplantation died in the intensive care unit of multiorgan failure, and the patient undergoing heart transplantation could be discharged.

In our early cases with ECMO, we observed a high incidence of bleeding complications. Therefore, we have changed our anticoagulation regimen. Systemic heparinization was not initiated until chest drainage reduced to less than 50 mL/h. The target partial thromboplastin time to be attained was between 50 and 60 seconds.

Limb ischemia was observed in 3 of the early patients in whom direct peripheral cannulation had been performed. As

TABLE 4. Postoperative complications

	Total	CABG	AVR	CABG + MVR	CABG + AVR	LVAD	CABG + VSD	HTX	Others*
No.	45	20	2	5	3	5	3	2	5
Rethoracotomy	39 (87%)	18 (90%)	2 (100%)	4 (80%)	3 (100%)	5 (100%)	3 (100%)	2 (100%)	2 (40%)
RBC transfusion	16.3 ± 13.0	14.7 ± 10.0	15.5 ± 0.7	10.4 ± 6.9	11.0 ± 7	25.3 ± 4.2	20.3 ± 4.9	32.4 ± 5.3	22.5 ± 28.1
Infection	26 (58%)	10 (50%)	1 (50%)	2 (40%)	1 (33%)	4 (80%)	2 (67%)	2 (100%)	4 (80%)
Neurologic complication	4 (9%)	1 (5%)	1 (50%)	1 (20%)	0 (0%)	1 (20%)	0 (0%)	0 (0%)	0 (0%)
Ischemia of lower limbs	3 (7%)	2 (10%)	0 (0%)	0 (0%)	0 (0%)	0 (0%)	0 (0%)	0 (0%)	1 (20%)
Fasciotomy	6 (13%)	2 (10%)	0 (0%)	0 (0%)	0 (0%)	1 (20%)	1 (33%)	1 (50%)	1 (20%)
Renal Failure	39 (87%)	17 (85%)	2 (100%)	4 (80%)	1 (33%)	5 (100%)	3 (100%)	2 (100%)	5 (100%)
CVVHD	39 (87%)	17 (85%)	2 (100%)	4 (80%)	1 (33%)	5 (100%)	3 (100%)	2 (100%)	5 (100%)
Change of oxygenator	4 (9%)	1 (5%)	1 (50%)	0 (0%)	0 (0%)	0 (0%)	0 (0%)	1 (50%)	1 (20%)
ARDS	4 (9%)	1 (5%)	0 (0%)	0 (0%)	0 (0%)	1 (20%)	0 (0%)	0 (0%)	2 (40%)
Leg amputation	1 (2%)	0 (0%)	0 (0%)	0 (0%)	0 (0%)	0 (0%)	0 (0%)	0 (0%)	1 (20%)

CABG, Coronary artery bypass grafting; AVR, aortic valve replacement; MVR, mitral valve repair; LVAD, left ventricular assist device; VSD, ventricular septal defect; HTX, heart transplantation; RBC, red blood cell; CVVHD, continuous venovenous hemodialysis; ARDS, adult respiratory distress syndrome. *Including double-valve replacement (n = 2), liver transplantation (n = 2), and type A aortic dissection (n = 1).

TABLE 5. Postoperative peak lactate levels between survivors and nonsurvivors up to 72 hours after ECMO initiation

	Group 1	Group 2	Group 3	Group 4
No.	25	20	13	12
Lactate levels (mg/dL)	148 ± 89	168 ± 56	139 ± 34	156 ± 40

ECMO, Extracorporeal membrane oxygenation; group 1, patients who could be weaned from extracorporeal membrane oxygenation; group 2, patients who could not be weaned from extracorporeal membrane oxygenation; group 3, hospital survivor; group 4, hospital nonsurvivor.

a consequence, distal limb perfusion was optimized with an 8-mm Dacron T-graft anastomosed end-to-side to the common femoral or subclavian artery to maintain both central arterial blood flow and distal limb perfusion.⁹ Fasciotomy of the lower leg was required in 6 patients because of compartment syndrome. The rate of systemic infection defined as a positive blood culture was 58% (26/45). Four (8.9%) patients had neurologic complications caused by cerebral hemorrhage (n = 3) and stroke (n = 1). Renal failure was the most common complication and occurred in 39 (86.7%) patients. All patients with renal failure required continuous venovenous hemofiltration. Rethoracotomy for bleeding or tamponade had to be performed in 39 (86.7%) patients. Table 4 lists the overall complications of ECMO support. There was no significant difference between the groups with different indications with regard to incidence of sepsis, neurologic complications, blood transfusions, rethoracotomy, or renal failure.

Lower initial serum lactate levels were observed in patients who could be weaned from ECMO and could be discharged from the hospital. In patients who failed to be weaned from ECMO, increased serum lactate levels persisted permanently. In the late postoperative course, patients with septic shock and end-stage multiorgan failure frequently had treatment-resistant lactate acidosis. Maximal postoperative lactate levels of patients who died during the postoperative course are shown in Table 5. There was no significant difference between the groups.

In patients who could not be weaned from ECMO, the main cause of death was persistent heart failure without any improvement in cardiac function (18/20 patients). In 6 patients the decision to implant an ECMO device was made

Figure 1. Kaplan–Meier survival curve of all patients with extracorporeal membrane oxygenation and the number of patients at risk.

postoperatively, 1 to 2 days after the initial operative procedure.

Twenty-five patients could be successfully weaned from ECMO, but only 13 patients could be discharged from the hospital. Therefore 12 of 25 patients had late complications with multiorgan failure and subsequently died.

The main causes of mortality in patients after successful weaning from ECMO were pulmonary infections and sepsis with consecutive multiorgan failure. These complications occurred more frequently in patients with advanced age and comorbidities, such as pulmonary hypertension and diabetes.

Independent predictors of hospital survival revealed in univariate regression analysis were absence of pulmonary hypertension ($P = .04$), absence of diabetes ($P = .011$), and use of IABP ($P = .04$).

Regarding underlying disease states, the best prognosis was observed for patients who were planned for permanent assist device implantation or transplantation (60%, Table 6).

After a follow-up period of up to 3 years, all of the discharged patients were reassessed (mean follow-up, 1.4 years). The total 3-year mortality was 78% (35/45); Figure 1 shows the Kaplan–Meier curve of survival. The 10 surviving patients reported cardiac symptoms of New York Heart Association class II (6 patients) or III (4 patients). Four of the 10 patients had a history of congestive heart failure with need for readmission; 1 patient was admitted because of pneumonia, and 1 patient reported end-stage renal failure requiring dialysis.

Discussion

Despite permanent surgical and medical development, cardiogenic shock remains a major complication in cardiac surgery

TABLE 6. Diagnosis-related in-hospital survival

	n (%)
Postcardiotomy syndrome	3/11 (27)
Preoperative cardiogenic shock	6/23 (26)
Bridge to LVAD/HTX	3/5 (60)

LVAD, Left ventricular assist device; HTX, heart transplantation.

procedures, especially when patients demonstrate heart failure symptoms or cardiogenic shock preoperatively.¹⁰ Although the majority of patients can be weaned from cardiopulmonary bypass with moderate inotropic drugs, IABP support, or both, up to 3% to 5% have severe persistent myocardial dysfunction.¹¹

In this patient group ECMO might provide sufficient hemodynamic and respiratory support to allow recovery from myocardial injury and extend the decision time for a bridging therapy. Recent studies report in-hospital survival rates with the use of ECMO ranging from 20% to 50% and mortality rates of 50% to 70%.^{12,13} In our study there was a high 30-day mortality of 53%; in-hospital mortality was 71%, and 3-year mortality was 78%. Our survival rate is comparable with those of other study groups.^{3,14}

Based on the experience in our institution, ECMO therapy is now considered to be a valuable option for treatment of myocardial infarction and low output syndrome in cardiac procedures in the operating room. We postulate that patients with severe left ventricular dysfunction, severe cardiomyopathy, primary perioperative respiratory failure, postcardiotomy syndrome, and myocardial infarction might benefit more if they receive this treatment option during the operation or at least very early in the postoperative course to prevent clinical deterioration. Early use of circulatory support might avoid additional myocardial damage caused by inotropic medication or hypoxia and thus provides a treatment option that allows for recovery from the myocardial injury over a prolonged period. Patients in perioperative shock or those after long cardiac procedures need a high normal cardiac output to recover. On the other hand, patients who use a bridge to permanent assist device implantation or transplantation demonstrate the best outcome.

The use of IABP also was a predictor for better survival. Based on the hypothesis of additional pulsatile flow, reduction of afterload, and better coronary flow, we now use IABP routinely in patients undergoing ECMO who do not demonstrate contraindications to IABP.^{13,14}

In the early cases of ECMO, we observed frequent bleeding problems, especially when platelet inhibitors had been administered before surgical intervention. After changing our postoperative anticoagulation protocol, there was a reduction in bleeding complications, but still, most patients had to undergo reoperation at some point during the postoperative course.

Renal failure and need for hemofiltration was another frequent complication in our study group. Of interest is the high incidence of renal failure during the postoperative course of 9 patients, which occurred days after successful weaning from ECMO. Perioperative high lactate concentrations were observed in nonsurvivor patients; however, this did not reach statistical significance.

The duration of ECMO in our patient group was 6.4 ± 4.5 days and thus longer compared with those seen in other study groups.^{3,13,14} Our strategy was to provide sufficient time to recover from myocardial injury; however, the study does not prove any benefit from that difference in strategy. The treatment duration should be decided individually, depending on heart and lung recovery. Improvement of our ECMO strategy to reduce system-related complications led us to extend the duration of ECMO to achieve maximal recovery.

The follow-up period was short but demonstrated that once successfully discharged from the hospital, patients had an acceptable midterm survival with class II to III heart failure and a low rate of readmission to the hospital. These results justify the use of ECMO, even if only slightly more than 20% of the patients survived up to 3 years after the cardiac operation.

In summary, current use of the heparin-precoated system and improvements in patient management reduced the complexity of ECMO. System-related complications are rare, and thus the threshold and timing for system implantation should be liberal. Therefore complex patients who currently might not be considered for ECMO could be able to benefit from ECMO in the future.

This article describes a retrospective analysis of our clinical experience with mixed indications for ECMO implantation. Despite a variety of changes in the management of our patients, we still had a relatively high rate of mortality.

References

- Hill D, O'Brien TG, Murray JJ, Dontigny L, Bramson ML, Osborn JJ, et al. Prolonged extracorporeal oxygenation of acute posttraumatic respiratory failure (shock-lung syndrome). *N Engl J Med*. 1972;286:629-34.
- Bartlett RH, Roloff DW, Custer JR, Younger JG, Hirschl RB. Extracorporeal life support: the University of Michigan experience. *JAMA*. 2000;283:904-8.
- Smedira NG, Moazami N, Golding CM, McCarthy PM, Apperson-Hansen C, Blackstone EH, et al. Clinical experience with 202 adults receiving extracorporeal membrane oxygenation for cardiac failure: survival at five years. *J Thorac Cardiovasc Surg*. 2001;122:92-102.
- Golding LAR. Postcardiotomy mechanical support. *Semin Thorac Cardiovasc Surg*. 1991;3:29-33.
- Chen YS. Pediatric in-intensive-care-unit cardiac arrest: new horizon of extracorporeal life support. *Crit Care Med*. 2006;34:2702-3.
- Smith C, Bellomo R, Raman JS, Matalanis G, Rosalion A, Buckmaster J, et al. An extracorporeal membrane oxygenation-based approach to cardiogenic shock in an older population. *Ann Thorac Surg*. 2001;71:1421-7.
- Muehrcke DD, McCarthy PM, Stewart RW, Foster RC, Ogella DA, Borsh JA, et al. Extracorporeal membrane oxygenation for postcardiotomy cardiogenic shock. *Ann Thorac Surg*. 1996;61:684-91.
- Zaloga GP. Early enteral nutritional support improves outcome: hypothesis or fact? *Crit Care Med*. 1999;27:259-61.
- Zimpfer D, Heinisch B, Czerny M, Hoelzenbein T, Taghavi S, Wolner E, et al. Late vascular complications after extracorporeal membrane oxygenation support. *Ann Thorac Surg*. 2006;81:892-5.

10. Morris AH. Extracorporeal support and patient outcome: credible causality remains elusive. *Crit Care Med*. 2006;34:1551-2.
11. Thiagarajan RR, Bratton SL. Extracorporeal membrane oxygenation for cardiac arrest: when to use it, and what are the outcomes? *Crit Care Med*. 2006;34:1285-6.
12. Doll N, Kiaii B, Borger M, Bucerius J, Kramer K, Schmitt DV, et al. Five-year results of 219 consecutive patients treated with extracorporeal membrane oxygenation for refractory postoperative cardiogenic shock. *Ann Thorac Surg*. 2004;77:151-7.
13. Doll N, Fabricius A, Borger MA, Bucerius J, Doll S, Kramer K, et al. Temporary extracorporeal membrane oxygenation in patients with refractory postoperative cardiogenic shock—a single center experience. *J Card Surg*. 2003;18:512-8.
14. Pagani FD, Lynch W, Swaniker F, Dyke DB, Bartlett R, Koelling T, et al. Extracorporeal life support to left ventricular assist device bridge to heart transplant: a strategy to optimize survival and resource utilization. *Circulation*. 1999;100(suppl): II206-10.