Cost-utility analysis of salvage cardiac extracorporeal membrane oxygenation in children

William T. Mahle, MD,^a Joseph M. Forbess, MD,^b Paul M. Kirshbom, MD,^b Angel R. Cuadrado, MD,^a Janet M. Simsic, MD,^a and Kirk R. Kanter, MD^b

Background: Indications for extracorporeal membrane oxygenation therapy have expanded to include cardiopulmonary arrest and support after congenital heart surgery. Data from a national registry have reported that cardiac patients have the poorest survival of all extracorporeal membrane oxygenation recipients. Concerns have been raised about the appropriateness of such an aggressive strategy, especially in light of the high costs and potential for long-term neurologic disability. We reviewed our experience with salvage cardiac extracorporeal membrane oxygenation to determine the cost-utility, which accounts for both costs and quality of life.

Methods: Medical records of patients with congenital heart disease receiving salvage cardiac extracorporeal membrane oxygenation between January 2000 and May 2004 were reviewed. Charges for all medical care after the institution of extracorporeal membrane oxygenation were determined and converted to costs by published standards. The quality-of-life status of survivors was determined with the Health Utilities Index Mark II.

Results: Salvage cardiac extracorporeal membrane oxygenation was instituted in 32 patients (18 for cardiopulmonary arrest and 14 for cardiac failure after heart surgery) at a median age of 2.0 months (range, 4 days to 5.1 years). Congenital heart disease was present in 27 (84%). The mean duration of extracorporeal membrane oxygenation support was 5.1 ± 4.1 days. Survival to hospital discharge was 50%, including 1 patient bridged to heart transplantation. Survival to 1 year was 47%. The mean score of the Health Utilities Index for the survivors was 0.75 ± 0.19 (range, 0.41-1.0). The median cost for hospital stay after the institution of extracorporeal membrane oxygenation was \$156,324 per patient. The calculated cost-utility for salvage extracorporeal membrane oxygenation in this population was \$24,386 per quality-adjusted life-year saved, which would be considered within the range of accepted cost-efficacy (<\$50,000 per quality-adjusted life-year saved).

Conclusions: Salvage cardiac extracorporeal membrane oxygenation results in reasonable survival and is justified on a cost-utility basis.

Originally introduced for the management of respiratory distress syndrome more than 25 years ago, extracorporeal membrane oxygenation (ECMO) is now used routinely in congenital heart disease centers.^{1,2} Several institutions have reported that ECMO is a useful adjunct in the management of patients

From Children's Healthcare of Atlanta and the Department of Pediatrics, Emory University School of Medicine, Atlanta, Ga,^a and Emory Clinic, Department of Cardiothoracic Surgery, Emory University School of Medicine, Atlanta, Ga.^b

Received for publication June 11, 2004; revisions received Aug 2, 2004; accepted for publication Aug 5, 2004.

Address for reprints: William T. Mahle, MD, Children's Healthcare of Atlanta, Emory University School of Medicine, 52 Executive Park S, Ste 52, Atlanta, GA 30329 (E-mail: mahlew@kidsheart.com).

J Thorac Cardiovasc Surg 2005;129:1084-90

0022-5223/\$30.00

Copyright © 2005 by The American Association for Thoracic Surgery

doi:10.1016/j.jtcvs.2004.08.012

with cardiomyopathy, arrhythmia, and postoperative ventricular failure.^{1,3,4} Despite promising results from some centers, cardiac ECMO in children still has the poorest survival of any ECMO indication.⁵ The multi-institutional Extracorporeal Life Support Organization registry data reported that the hospital survival for cardiac ECMO is 42%.⁶ In addition, many of the patients with congenital heart disease have cardiac lesions that may require several palliative operations and are not expected to have a normal life expectancy. Moreover, patients with congenital heart disease are at risk for later neurologic deficits, which are likely exacerbated by the need for ECMO in early childhood—especially when instituted in the setting of acute cardiac arrest.^{7,8} Because of these concerns and the recognition that ECMO is an expensive resource, some have questioned the use of ECMO for salvage therapy of children with heart disease.

Several studies have examined the cost-effectiveness of ECMO in other pediatric populations.^{9,10} Studies in North America and Europe have suggested that ECMO is cost-effective when it is used for the management of neonatal respiratory failure.⁹⁻¹¹ It is not known, however, whether salvage cardiac ECMO is cost-effective. In this study, we reviewed our institution's recent experience with salvage cardiac ECMO to report outcomes and determine cost-utility.

Methods

Decision Analysis

With the approval of the Institutional Review Board of Emory University School of Medicine, we constructed a decision-analytic model to examine the cost utility of salvage cardiac ECMO. We adopted the perspective of a clinician who must decide whether to institute a program of routine salvage cardiac ECMO. For the purposes of this study, salvage cardiac ECMO was defined as institution of ECMO in the setting of (1) acute cardiac arrest for children with underlying heart disease or (2) hemodynamic failure after surgery for congenital heart disease. This study excluded patients with structurally normal hearts in whom myocarditis, arrhythmia, or both, develop and who are placed on ECMO electively. The main reason for excluding these subjects is that it is difficult to know how they might have done had they not received ECMO. For other pediatric conditions, such as acute respiratory distress syndrome, investigators have developed algorithms for risk of death, such as the Pediatric Index of Mortality. To our knowledge, these algorithms have not been validated in the setting of isolated cardiac disease. In the absence of such data, we believed it more appropriate to exclude children placed on ECMO electively. Our center does not routinely use ECMO after certain congenital heart procedures, such as the Norwood operation, as has been advocated by some institutions.¹² We included all patients who received salvage cardiac ECMO from January 1, 2000, to May 1, 2004. The primary outcome was cost-utility, which calculates the cost per quality-adjusted life-year (QALY) saved. Costs are reported in 2003 US dollars.

Data and Assumptions

Medical costs. Costs of hospitalization from the time of institution of ECMO to hospital discharge were obtained from direct hospital charges. Hospital charges included all chargeable items, nonphysician personnel time, and physician charges. Hospital charges were converted to costs based on the cost-charge ratio (0.5604) for Children's Healthcare of Atlanta.¹³

Future medical costs. The analysis accounted for medical costs that would be incurred after hospital discharge for survivors. For patients with a single ventricle, the mean costs of a bidirectional Glenn procedure (Current Procedural Terminology 33767) and a modified Fontan procedure (Current Procedural Terminology code 33619) were derived from hospital sources. The cost of additional prosthetic mitral valve operation was not included, because the timing for such operations can vary considerably among patients. We assumed an annual visit with a cardiologist and a limited echocardiographic examination and electrocardiogram on a semiannual basis for all subjects with congenital heart disease. Costs for these encounters were derived from published Medicare sources.^{14,15} Annual costs for lifetime medications, such as digoxin, angiotensin-converting inhibitors, diuretics, or immunosuppressants, for those undergoing heart transplantation were included in the model. We did not include costs for noncardiology medical services or medications.

Cost-utility analysis. Utility data—to evaluate the quality of life—in children and adults with congenital heart disease are lacking. However, to make comparisons between salvage cardiac ECMO and other public health interventions, we used the Health Utilities Index Mark II (HUI-2).¹⁵ The HUI-2 is a 15-item questionnaire designed to ask the minimum number of questions required to classify a subject's health status. Parents completed the HUI-2 in all cases. From questionnaire responses, one can derive a multiattribute utility function. Scores range from death to full health (0 to 1.00). The HUI-2 has been shown to have reasonable interrater reliability and has previously been applied to a number of other pediatric disease states.^{16,17}

Life expectancy. Because the study was limited to patients receiving salvage cardiac ECMO, we assumed that mortality would be 100% had the subjects not been placed on ECMO. Subsequent costs and life-years saved were, therefore, calculated from the time of institution of ECMO onward. Although historical studies have demonstrated that the survival for patients with congenital heart disease is less than for the healthy population, outcomes have been improving in recent decades. Therefore, for patients with 2-ventricle circulation, life expectancy was assumed to be normal: 77.2 years, according to recent vital statistics.¹⁸ The life expectancy for children with single-ventricle heart lesions was assumed to be 40 years. The median life expectancy of 40 years in single-ventricle patients was derived from an expected 10-year survival of 80% and a 10% risk of death per decade on the basis of analysis of historical cohorts.¹⁹

Discount rate. All future costs and benefits were discounted at a rate of 3%. Discounting is used to calculate life-years lost.

Sensitivity Analysis

For cost-utility analysis, we evaluated the sensitivity of the model to variations in key assumptions over various ranges. We varied the hospital mortality for salvage cardiac ECMO in congenital

TABLE 1. Patient population

Variable	No. (%)
Congenital heart disease	27 (84%)
2-ventricle anatomy	15 (56%)
1-ventricle anatomy	12 (44%)
Prior cardiac surgery	26 (81%)
Prior cardiac surgery, same admission	22 (69%)
Indication for ECMO	
Cardiopulmonary arrest	18 (56%)
Failure to separate from CPB	11 (34%)
Postoperative low cardiac output	2 (6%)
Postoperative pulmonary hypertension	1 (3%)

ECMO, Extracorporeal membrane oxygenation; CPB, cardiopulmonary bypass.

heart disease patients from 30% to 70%. We also varied the utility score ± 0.20 to a maximum of 1.0 to account for the possibility that health status might change significantly in later years.

Results

Between January 1, 2000, and May 1, 2004, cardiac ECMO was instituted in 39 patients. Seven subjects with normal cardiac anatomy and myocarditis, arrhythmias, or both were placed on ECMO electively and had a hospital survival of 86%. Salvage cardiac ECMO was used in 32 patients (18 for cardiopulmonary arrest, 11 for failure to wean from bypass after surgery, and 3 for ventricular dysfunction, pulmonary hypertension, or both immediately after surgery) at a median age of 2.0 months (range, 4 days to 5.1 years; Table 1). Congenital heart disease was present in 27 (84%). Among the congenital heart defects were hypoplastic left heart syndrome (n = 6), other single-ventricle disease (n = 5), total anomalous pulmonary venous connection (n = 3), interrupted aortic arch (n = 2), anomalous left coronary from the pulmonary artery (n = 2), double-outlet right ventricle (n = 2), mitral stenosis (n = 2), tetralogy of Fallot (n = 2), pulmonary atresia with ventricular septal defect (n = 1), D-transposition of the great arteries (n = 1), and heart transplantation (n = 1). One subject had VATER syndrome,* and 1 patient had DiGeorge syndrome. Three patients were placed on ECMO for cardiac arrest at presentation and underwent congenital heart operation later during that hospitalization.

The mean duration of ECMO support was 5.1 ± 4.1 days. Survival to hospital discharge was 50%, including 1 patient who was bridged to heart transplantation. Survival to 1 year for the entire cohort was 47%. Two of the initial 16 hospital survivors subsequently died. One death occurred 5 months after ECMO decannulation in a patient with low cardiac output after a Glenn procedure for

*VATER = vertebral defects, imperforate anus, tracheoesophageal fistula, and radial and renal dysplasia.

TABLE 2. Hospital cost for salvage cardiac ECMO

Variable	Entire cohort (n = 32)	Per hospital survivor
Hospital costs on ECMO	\$4,440,496	
Hospital costs decannulation to discharge	\$2,089,645	
Total hospital costs after institution of ECMO	\$6,530,141	\$408,133
Annual medical costs for survivors (\$/y)		\$448
Cost of additional surgical admissions		\$25,680
Cost per life-year saved		\$19,565
Cost per QALY saved		\$24,386

ECMO, Extracorporeal membrane oxygenation; QALY, quality-adjusted life-year.

hypoplastic left heart syndrome. A second patient with VATER syndrome and multiple congenital anomalies and tracheostomy died out of hospital from acute respiratory failure 21 months after discharge from ECMO hospitalization.

Sixteen patients did not survive to hospital discharge. Most of these deaths (n = 10) occurred while subjects were still receiving ECMO support or within 72 hours of decannulation. An additional 6 subjects died more than 72 hours after decannulation during the same hospital stay. The most common cause of death was multiple organ system failure (n = 6). Two patients had neurologic injuries that prompted withdrawal of ECMO support. Additional causes of death in these subjects included cardiopulmonary arrest (n = 3), acute graft rejection after transplantation (n = 1), ventricular dysfunction (n = 1), sepsis (n = 1), pneumatosis intestinalis (n = 1), and complications with the ECMO circuit (n = 1).

While receiving ECMO support, patients were evaluated for neurologic injury. Evaluations included neurologic examinations and brain imaging in most cases. There were 7 patients with significant neurologic events. Neuroimaging studies demonstrated watershed infarct (n = 4), embolic infarct (n = 2), small subdural hematoma (n = 1), and grade IV interventricular hemorrhage (n = 1). Of the 16 subjects who survived to hospital discharge, 3 were noted to have gross motor weakness. Two subjects had significant cognitive impairment.

Hospital Costs

For the entire cohort, the cost of hospitalization after institution of salvage cardiac ECMO for the entire cohort was \$6,530,141 (Table 2). The median hospital cost of salvage cardiac ECMO per patient was \$156,324. There was significant variation in cost even among the hospital survivors. Hospital costs ranged from \$81,413 to \$1,238,004. The

Figure 1. Distribution of utility scores from Health Utilities Index Mark II, with mean and SD.

mean cost per 24 hours of ECMO support was \$16,430 $\pm$ \$6,901.

Calculated Follow-up Costs

Most survivors (82%) had congenital heart defects that were likely to require lifelong care by a cardiologist. For survivors with congenital heart disease, the calculated annual mean cost of medications, evaluation by a cardiologist, and imaging was \$446 per year. Patients with single-ventricle anatomy routinely undergo a bidirectional Glenn procedure and modified Fontan procedure at 4 to 6 months and 18 to 24 months of age, respectively. At our institution, the mean cost of the Glenn procedure is \$24,554 $\pm$ \$5,945, and the mean cost of a Fontan procedure is \$28,808 $\pm$ \$7,906. The costs of follow-up after transplantation were derived from published literature.²⁰ These data were included in the economic analysis.

Health Utilities Analysis

The mean score of HUI-2 for the survivors was 0.75 $\pm$ 0.19 (range, 0.41–1.0). There were 2 patients with severe impairment and disability (utility <0.5). Three survivors reported full health (utility = 1.0). The distribution of utility scores is shown in Figure 1.

Cost-Utility Analysis

The median costs for hospital stay—for survivors and non-survivors—after institution of ECMO were \$156,324. The calculated cost-utility for salvage ECMO in this population was \$24,386 per QALY saved. Sensitivity analysis is shown in Figure 2. Using the utility scores reported by the parents, but varying the in-hospital mortality for salvage cardiac ECMO between 30% and 70%, resulted in a range of cost-utility ratios from \$14,255 to \$32,721 per QALY saved. Assuming a hospital mortality of 50% but varying

Figure 2. Sensitivity analysis of cost utility for salvage cardiac extracorporeal membrane oxygenation varying both hospital mortality (between 30% and 70%) and reported utility scores ($\pm$ 0.2). QALY, Quality-adjusted life-year.

the utility scores by $\pm$ 0.20 up to a maximum of 1.0 resulted in a range in calculated cost utility from \$20,687 to \$32,220 per QALY saved. Assuming the least favorable scenario—hospital mortality of 70% and reported health utility 0.20 less than that reported by parents—produced a cost-utility of \$49,686 per QALY saved.

Discussion

This study demonstrates that the use of cardiac ECMO for salvage therapy falls within the bounds of routinely accepted cost-utility. Even if one assumes that measures of quality of life may be lower as patients approach adulthood and that hospital mortality may be higher than the recent experience at our institution, the use of salvage cardiac ECMO still has a favorable cost-utility.

Since ECMO's introduction in the late 1970s, outcomes for children receiving ECMO have improved dramatically. The hospital survival after ECMO for noncardiac conditions—such as meconium aspiration syndrome, persistent pulmonary hypertension of the neonate, and congenital diaphragmatic hernia—have been reported to be 93%, 83%, and 59%, respectively.²¹ The outcome for children requiring cardiac ECMO has been reported to be worse. The hospital survival for children receiving any form of cardiac ECMO is reported to be 42%, though some single-center reports have ranged from 39% to 64%.^{3,22–24} Some institutions have suggested that certain groups, such as those with ventricular failure after cardiopulmonary bypass, may be at higher risk for mortality.²⁴ Conversely, a recent large single-center report indicated that indications for cardiac ECMO and underlying congenital heart defects were not associated with survival.²² At our institution, patients with myocarditis

or arrhythmias who were placed on ECMO electively had a hospital survival of 86%, whereas those receiving salvage cardiac ECMO had a hospital survival of 50%.

Data regarding the quality of life and neurodevelopmental outcome for children who have required ECMO therapy have been reported in recent years. Most studies have focused on patients with neonatal respiratory distress from persistent fetal circulation or diaphragmatic hernia. In general, these studies have reported mild to moderate developmental delay. The collaborative UK ECMO trial found that severe developmental disabilities were present in only 1 of 63 survivors.²⁵ Functional loss was present in 19%, and impairment without functional loss was present in 13%. Nield and colleagues²⁶ assessed functional status in preschool survivors of neonatal ECMO and found that 17% were abnormal and 24% were “at risk.” Major neurologic sequelae were present in 15% of survivors. D’Agostino and colleagues²⁷ reported that at 1 year of age, the mean mental developmental index of the Bayley Scales of Infant Development was 87 and that the psychomotor index was borderline, at 75. Conversely, some studies have suggested that the long-term neurologic risks for patients receiving neonatal ECMO are quite low. Lamers and colleagues²⁸ reported normal developmental outcome (a mean mental developmental index of 102 and psychomotor index of 97) in 76 survivors of venoarterial ECMO for respiratory failure.

There are limited data on functional status or neurodevelopmental outcome for survivors of cardiac ECMO. Ibrahim and colleagues⁷ reported that moderate to severe neurologic impairment was present in more than 50% of pediatric cardiac ECMO survivors. These authors postulated that much of the neurologic impairment may have been due to underlying congenital disease and the need for circulatory arrest rather than the ECMO per se. Similarly, Hamrick and colleagues⁸ reported that 50% of survivors of cardiac ECMO had abnormal cognitive outcome, although motor abnormalities were less common (30% of patients). Although the present study did not include formal neurodevelopmental testing, the HUI scores suggested significant impairment in some survivors. The 3 subjects with the lowest utility scores—all less than 0.6—had significant neurologic impairment. Two of these patients had evidence of significant ischemic neurologic injury on brain imaging, whereas the third had congenital neurologic abnormalities. It is interesting to note that ischemic neurologic injury can be documented after cardiac surgery in a significant number of neonates with congenital heart disease who do not require ECMO support.²⁹ Therefore, it would seem that a variety of factors—such as congenital abnormalities, the need for open-heart surgery with cardiopulmonary bypass, coagulation, and embolic complications from the ECMO circuit—seem to put the cardiac ECMO patients at risk for later

developmental impairment, which ultimately affects quality of life.

There are numerous studies regarding the costs and cost-efficacy of ECMO in pediatric patients with noncardiac lesions. Vats and colleagues⁹ reported that the mean hospital charges for pediatric ECMO for acute respiratory failure were \$199,096 in 1993, or the equivalent of \$252,594 in 2003. The National Institutes of Health Workshop on the Diffusion of ECMO Technology reported a cost of \$107,000 (1993 dollars) per survivor versus \$122,000 per death.³⁰ When one adjusts for inflation, the cost of hospitalization for patients receiving salvage cardiac ECMO is in the range of that reported for noncardiac patients. Studies that have undertaken cost-effectiveness or cost-utility analysis for ECMO in noncardiac patients have generally reported that ECMO is cost-effective. Vats and colleagues⁹ calculated that noncardiac ECMO results in a cost of \$4190 per life-year saved (1994 dollars), which would be well within the bounds of accepted cost-utility.

Although the hospital costs for salvage cardiac ECMO seem to be similar to those for noncardiac indications of neonatal ECMO, the calculated cost-utility is slightly less favorable. Salvage cardiac ECMO may be somewhat less cost-effective than noncardiac ECMO for a variety of reasons. Most importantly, the hospital survival is less for cardiac patients, which results in a considerable expenditure for patients who do not survive. In addition, life expectancy for children with complex congenital heart lesions, such as a single ventricle, is less than for children with respiratory distress in the neonatal period. Although the latter group can reasonably be expected to have a normal life span if they survive initial hospitalization, children with congenital heart disease, particularly those with a complicated neonatal course, are likely to be at risk for ventricular failure and arrhythmias. In addition, ECMO has been proposed as a bridge to cardiac transplantation.^{31,32} After transplantation, the median time to graft failure in children is only 11.2 years, according to data from the United Organ Sharing Network.³³ Together, these factors limit the number of life-years gained from a successful ECMO resuscitation. Finally, disabilities limit the quality of life of survivors and need to be considered in a cost-utility analysis. Although disabilities do occur after noncardiac ECMO, they may be more common after cardiac ECMO.

It is important to note that this study suggests that salvage cardiac ECMO would be likely to remain cost-effective even if the hospital survival were less than that reported in this relatively small series of patients. If one were to assume a hospital survival of 40%—closer to the data from national studies—salvage cardiac ECMO would remain justifiable on a cost-utility basis. Even if one decreases the utility scores by 0.2 utilities per child—assuming that parents might overrate their child’s functional status or that the

degree of functional impairment might not be obvious until a later age—salvage cardiac ECMO remains cost-effective. The use of cardiac ECMO primarily as a bridge to heart transplantation, however, may exceed the limits of routinely accepted cost-efficacy. Previous studies have suggested that heart transplantation in adults has a cost-utility ratio of \$25,000 and \$44,300 per year of life saved.^{34,35} If one included the additional costs of salvage ECMO support, it is possible that this strategy of ECMO as a bridge to transplantation might exceed the generally accepted bound of cost-effectiveness. Our study had only a single patient bridged to transplantation. As such, a more detailed analysis of this unique patient population is warranted.

A number of limitations to this study design must be recognized. Cost analysis was performed at a single institution, and the sample size was relatively small. Practice patterns and resource use may vary significantly among centers within the United States and cannot be extrapolated to other countries. In addition, the study was limited to children receiving salvage cardiac ECMO. The study did not include children with normal cardiac anatomy and marginal hemodynamics who were placed on ECMO electively, nor did it address the practice of routine postoperative ECMO for certain high-risk neonatal operations such as the Norwood procedure. Whether a similar cost utility exists for cardiac ECMO in these settings is not known. Finally, although the overall survival for cardiac ECMO does not seem to have changed significantly in the last decade according to data from the registry data, it is possible that there will be an improved survival in cardiac ECMO paralleling the marked improvement seen in neonatal congenital heart surgery in recent years. Some authors have suggested that institution of a resuscitation cardiac ECMO program that can be mobilized in minutes might improve survival and reduce morbidity.³

In conclusion, the data from our study suggest that cardiac ECMO—even when used in the setting of salvage therapy—still falls within the bounds of routinely accepted cost-utility.

References

1. Delius RE, Caldarone C. Mechanical support of the pediatric cardiac patient. *Semin Thorac Cardiovasc Surg Pediatr Card Surg Annu.* 2000;3:179-85.
2. Kolovos NS, Bratton SL, Moler FW, Bove EL, Ohye RG, Bartlett RH, et al. Outcome of pediatric patients treated with extracorporeal life support after cardiac surgery. *Ann Thorac Surg.* 2003;76:1435-41.
3. Duncan BW, Ibrahim AE, Hraska V, del Nido PJ, Laussen PC, Wessel DL, et al. Use of rapid-deployment extracorporeal membrane oxygenation for the resuscitation of pediatric patients with heart disease after cardiac arrest. *J Thorac Cardiovasc Surg.* 1998;116:305-11.
4. Trittenwein G, Pansi H, Graf B, Golej J, Burda G, Hermon M, et al. Proposed entry criteria for postoperative cardiac extracorporeal membrane oxygenation after pediatric open heart surgery. *Artif Organs.* 1999;23:1010-4.
5. Bartlett RH. Extracorporeal Life Support Registry Report 1995. *ASAIO J.* 1997;43:104-7.
6. ECMO registry of the Extracorporeal Life Support Organization (ELSO). Ann Arbor (MI): 2003.
7. Ibrahim AE, Duncan BW, Blume ED, Jonas RA. Long-term follow-up of pediatric cardiac patients requiring mechanical circulatory support. *Ann Thorac Surg.* 2000;69:186-92.
8. Hamrick SE, Gremmels DB, Keet CA, Leonard CH, Connell JK, Hawgood S, et al. Neurodevelopmental outcome of infants supported with extracorporeal membrane oxygenation after cardiac surgery. *Pediatrics.* 2003;111(6 Pt 1):e671-5.
9. Vats A, Pettignano R, Culler S, Wright J. Cost of extracorporeal life support in pediatric patients with acute respiratory failure. *Crit Care Med.* 1998;26:1587-92.
10. Petrou S, Edwards L. Cost effectiveness analysis of neonatal extracorporeal membrane oxygenation based on four year results from the UK Collaborative ECMO Trial. *Arch Dis Child Fetal Neonatal Ed.* 2004;89:F263-8.
11. Cohen MI, Gaynor JW, Ramesh V, Karl TR, Steven JM, Posner J, et al. Extracorporeal membrane oxygenation for patients with refractory ventricular arrhythmias. *J Thorac Cardiovasc Surg.* 1999;118:961-3.
12. Darling EM, Kaemmer D, Lawson DS, Jagers JJ, Ungerleider RM. Use of ECMO without the oxygenator to provide ventricular support after Norwood stage I procedures. *Ann Thorac Surg.* 2001;71:735-6.
13. Hospital reimbursement—TRICARE/CHAMPUS policy manual 6010.47M. Chapter 13. Washington (DC): TRICARE/CHAMPUS; 1999.
14. Pearlman AS. The Medicare five-year review—a progress report. *J Am Soc Echocardiogr.* 1996;9:25A-28A.
15. Horsman J, Furlong W, Feeny D, Torrance G. The Health Utilities Index (HUI®): concepts, measurement properties and applications. *Health Qual Life Outcomes.* 2003;1:54.
16. Raat H, Bonsel GJ, Essink-Bot ML, Landgraf JM, Gemke RJ. Reliability and validity of comprehensive health status measures in children: the Child Health Questionnaire in relation to the Health Utilities Index. *J Clin Epidemiol.* 2002;55:67-76.
17. Van Schaik CS, Barr RD, Depauw S, Furlong W, Feeny D. Assessment of health status and health-related quality of life in survivors of Hodgkin's disease in childhood. *Int J Cancer Suppl.* 1999;12:32-8.
18. Arias E, MacDorman MF, Strobino DM, Guyer B. Annual summary of vital statistics—2002. *Pediatrics.* 2003;112(6 Pt 1):1215-30.
19. Mair DD, Puga FJ, Danielson GK. The Fontan procedure for tricuspid atresia: early and late results of a 25-year experience with 216 patients. *J Am Coll Cardiol.* 2001;37:933-9.
20. Gajarski RJ, Towbin JA, Garson A Jr. Fontan palliation versus heart transplantation: a comparison of charges. *Am Heart J.* 1996;131:1169-74.
21. Conrad SA, Rycus PT. Extracorporeal life support 1997. *ASAIO J.* 1998;44:848-52.
22. Morris MC, Ittenbach RF, Godinez RI, Portnoy JD, Tabbutt S, Hanna BD, et al. Risk factors for mortality in 137 pediatric cardiac intensive care unit patients managed with extracorporeal membrane oxygenation. *Crit Care Med.* 2004;32:1061-9.
23. del Nido PJ. Extracorporeal membrane oxygenation for cardiac support in children. *Ann Thorac Surg.* 1996;61:336-9.
24. Duncan BW, Hraska V, Jonas RA, Wessel DL, del Nido PJ, Laussen PC, et al. Mechanical circulatory support in children with cardiac disease. *J Thorac Cardiovasc Surg.* 1999;117:529-42.
25. The collaborative UK ECMO (Extracorporeal Membrane Oxygenation) trial: follow-up to 1 year of age. *Pediatrics.* 1998;101(4):E1.
26. Nield TA, Langenbacher D, Poulsen MK, Platzker AC. Neurodevelopmental outcome at 3.5 years of age in children treated with extracorporeal life support: relationship to primary diagnosis. *J Pediatr.* 2000;136:338-44.
27. D'Agostino JA, Bernbaum JC, Gerdes M, Schwartz IP, Coburn CE, Hirsch RB, et al. Outcome for infants with congenital diaphragmatic hernia requiring extracorporeal membrane oxygenation: the first year. *J Pediatr Surg.* 1995;30:10-5.

28. Lamers LJ, Rowland DG, Seguin JH, Rosenberg EM, Reber KM. The effect of common origin of the carotid arteries in neurologic outcome after neonatal ECMO. *J Pediatr Surg.* 2004;39:532-6.
29. Mahle WT, Tavani F, Zimmerman RA, Nicolson SC, Galli KK, Gaynor JW, et al. An MRI study of neurological injury before and after congenital heart surgery. *Circulation.* 2002;106(12 suppl 1):I109-14.
30. Morris AH. Cost-benefit considerations in managing oxygenation failure. *Respir Care.* 1993;38:829-38.
31. Frazier EA, Faulkner SC, Seib PM, Harrell JE, Van Devanter SH, Fasules JW. Prolonged extracorporeal life support for bridging to transplant: technical and mechanical considerations. *Perfusion.* 1997;12:93-8.
32. Di Russo GB, Clark BJ, Bridges ND, Godinez RI, Paridon SM, Spray TL, et al. Prolonged extracorporeal membrane oxygenation as a bridge to cardiac transplantation. *Ann Thorac Surg.* 2000;69:925-7.
33. Bennett LE, Keck BM, Daily OP, Novick RJ, Hosenpud JD. World-wide thoracic organ transplantation: a report from the UNOS/ISHLT International Registry for Thoracic Organ Transplantation. *Clin Transpl.* 2000;31-44.
34. Evans RW. Cost-effectiveness analysis of transplantation. *Surg Clin North Am.* 1986;66:603-16.
35. Hogness JR, VanAntwerp M, editors. The artificial heart: prototypes, policies, and patients. Washington (DC): National Academy Press; 1991.

Online—www.aats.org

Now you can get **The Journal of Thoracic and Cardiovascular Surgery** online. The Journal online brings you faster delivery time, easy searching of current and back issues, links to PubMed, AATS, WTSa, and other important sites, and more. Visit the Journal online today.

Receive tables of contents by e-mail

To receive the tables of contents by e-mail, sign up through our Web site at <http://www.mosby.com/jtcvs>

Choose *E-mail Notification*

Simply type your e-mail address in the box and click the *Subscribe* button.

Alternatively, you may send an e-mail message to majordomo@mosby.com.

Leave the subject line blank and type the following as the body of your message:
subscribe jtcvs_toc

You will receive an e-mail to confirm that you have been added to the mailing list.

Note that TOC e-mails will be sent out when a new issue is posted to the Web site.