An Economic Analysis of Extracorporeal Membrane Oxygenation

Gail Denise Pearson, MPA, and Billie Lou Short, MD

Financial considerations, in concert with clinical effectiveness, are of increasing importance in the assessment of technological innovations. One such innovation, extracorporeal membrane oxygenation (ECMO), is now in use at over twenty centers nationwide to treat newborns with severe, acute lung disease. Use of ECMO therapy for one year at Children's Hospital National Medical Center, Washington, DC, in a population of patients with persistent pulmonary hypertension of the newborn (PPHN) is reported, comparing outcome and financial considerations with a similar group of infants treated conventionally prior to ECMO. A historical control group of infants with severe PPHN showed that before ECMO was available the survival rate in this critically ill population was only 21%. With ECMO, infants with the same clinical characteristics have an 80% chance of survival. Analysis of hospital and physician charges for these two groups (pre-ECMO and ECMO) reveals that ECMO therapy is about 2% less expensive than conventional treatment. When only survivors in each group are compared, ECMO is 43% less costly. These differences are attributable to reductions in average length of hospital stay with ECMO therapy, and they are conservative in that they do not take into consideration the marked economic advantage to society of averting unnecessary deaths.

The cost of health care has become a pressing concern for health professionals and the public. The medical profession is criticized for failure to control costs, and the merits of many expensive procedures now are questioned. Intensive care, or so-called high-technology medicine, is often singled out as an important factor contributing to escalating costs [1-4]. In this climate, one of the mandatory steps in offering a new therapeutic intensive care program is to demonstrate its financial viability as well as its clinical efficacy.

In the past decade, a new technology, extracorporeal membrane oxygenation (ECMO), has been developed for use in neonatal intensive care nurseries to treat newborns with severe acute lung disease attributable to persistent pulmonary hypertension of the newborn (PPHN). Neonatal ECMO has been described in detail elsewhere [5-8]. At Children's Hospital National Medical Center (CHNMC), Washington, DC, the standard venoarterial circuit is used. In essence, ECMO diverts blood returning to the right atrium to an extracorporeal circuit, adds oxygen and removes carbon dioxide, and then returns the blood to the systemic circulation at the ascending aorta. The lungs and heart are bypassed, which allows the lungs to heal and permits reversal of myocardial damage secondary to hypoxia.

With conventional therapy, including respiratory support at maximal ventilator settings, many infants with severe PPHN die [5-8]. Iatrogenic chronic lung damage often develops in survivors as a result of maximal ventilation. With ECMO, not only are mortality rates drastically reduced [5,6,8], but chronic lung damage is avoided as well. Little attention has been paid, however, to the economic aspects of this therapy. Many new technologies are considerably more costly than those they replace,
norwithstanding their superior value for patient care. Although not paramount, this is an important consideration. This study presents an economic analysis of ECMO therapy at Children's Hospital National Medical Center.

**Patients and Methods**

In general terms, candidates for ECMO must (1) be likely to have their underlying pulmonary disease resolved within 10 days, (2) have no evidence of chronic lung disease as a result of ventilator damage, (3) have a reasonable chance of surviving without significant physical or cognitive impairment, (4) have no major chromosomal abnormalities, (5) have a low risk of intracranial hemorrhage, and (6) weigh more than 2,000 g at birth. In addition, ECMO candidates also must fail to respond to maximal conventional medical therapy, including ventilation with 100% inspired oxygen, vasodilation (e.g., tolazoline, 1 to 2 mg/kg bolus, then infusion of 1 to 2 mg/kg/hr), and hyperventilation in an attempt to achieve carbon dioxide tension less than or equal to 25 mm Hg to assist in stimulating vasodilation. Finally, the infant must exhibit an alveolar-arterial oxygen gradient of greater than or equal to 610 for at least 8 hours, or 605 for at least 4 hours at a pressure limit (PL) of 38 cm H₂O. Infants who meet all these criteria in our institution have less than a 20% survival rate without ECMO [9].

The economic analysis was based on two groups of patients: the ECMO group, who received ECMO therapy between June 21, 1984, and June 30, 1985 (approximately the first year of program operation at CHNMC), and the pre-ECMO group, a historical control group clinically similar to ECMO patients but hospitalized before the start of the ECMO program and treated conventionally. Infants in both study groups met all of the criteria described previously.

**ECMO Group.** A total of 26 patients received ECMO therapy during this period. One was excluded from the financial analysis because she did not complete the full ECMO course. For purposes of this study, the ECMO group included 25 patients.

**Pre-ECMO Group.** Thirty-four infants with PPHN were identified in a review of CHNMC neonatal intensive care unit (NICU) admissions between June, 1982, and June, 1984, as part of a study to identify clinical parameters (the alveolar-arterial oxygen gradient values described previously) that now are used as final entry criteria for ECMO therapy and that predict a 20% survival rate [10]. These criteria were met by 20 of the 34 infants. These 20 patients were used as the basis for the pre-ECMO historical control group in the present study because they are virtually identical clinically to the ECMO group. Of these 20 pre-ECMO infants, only 14 had complete financial records. The pre-ECMO historical control group for the present study, therefore, consists of these 14 newborns. To determine whether this 14-patient subset was significantly different from the group of 20 in ways that could bias the financial analysis, the variables of gender, age, birth weight, gestational age, mortality rate, and length of stay were compared between the two groups using Student's t test or chi-square analysis, as appropriate. A p value of less than or equal to .05 was accepted as significant. The ECMO and pre-ECMO groups also were compared for gender, age; birth weight, gestational age, and underlying diagnosis.

**Economic Data**

Information was obtained from CHNMC medical and financial records on the total length of stay at CHNMC, total hospital charges, and total physician charges for all patients. Program development costs also were obtained. Complete information was unavailable on hospital care after discharge from CHNMC, so the analysis was restricted to charges for hospital care at CHNMC only. The hospital room (bassinet) rate was constant throughout the study period. Other hospital charges were adjusted to fiscal year 1985 levels, assuming average annual inflation of 10.8% based on hospital records. Physician charge and collection policies changed considerably during the study period. For the ECMO group, accurate records were available for physician charges. For the pre-ECMO group, accurate records were not always available. To overcome this problem, average physician charges were calculated for all pre-ECMO infants billed in fiscal year 1985, and the resulting average daily charge of $234.45 was applied to all pre-ECMO infants. This served to both standardize physician charges and adjust them to fiscal year 1985.

**Results**

The ECMO group (n = 25) consisted of 17 boys (68%) and 8 girls (32%). Average gestational age was 38.8 weeks, and average birth weight was 3,259 g. In the pre-ECMO group (n = 14), 11 (79%) were male and 3 (21%) were female. Average gestational age was 38.9 weeks, and average birth weight was 2,970 g. There were no significant differences be-
between the ECMO and pre-ECMO groups for any of these variables (Table 1). Table 2 compares underlying diseases for each group. There also were no significant differences between the pre-ECMO group and the larger group \( n = 20 \) from which the pre-ECMO subjects were drawn in terms of gender, age, birth weight, diagnosis, and length of stay.

Of the 26 infants who received ECMO therapy during the study period, 21 (80.8%) survived ECMO, and 5 (19.2%) died. Excluding the infant who did not complete ECMO treatment, the survival rate is 80% (20 of 25). In the pre-ECMO group, 4 (28.6%) survived and 10 (71.4%) died. The 28.6% survival does not differ significantly from the 20% predicted for pre-ECMO patients. The pre-ECMO survival rates do, however, differ significantly from the ECMO survival rates \( (x^2 = 33.53, p < .001) \).

There also was a significant difference in length of stay between the two groups. Pre-ECMO infants stayed at CHNMC an average of 37.4 days, whereas ECMO infants required only 21 days of hospital care \( (t = -7.712, p = .0001) \). Discharge criteria for both were identical.

Table 3 shows the financial information for ECMO and pre-ECMO groups. The total charge for ECMO patients was $4,371.62 per day, or $91,804.02 per episode (21 days), including $3,256.89 per day for hospital charges and $1,114.73 per day for physician fees. This total amount included program development costs, or $96,886, which was amortized over all ECMO patient-days. Program development costs included personnel (coordinator, perfusionist), laboratory training, and equipment. Total charges for pre-ECMO patients were $2,500.65 per day, or $93,524.31 per episode (37.4 days), including $2,266.20 per day for hospital charges and $234.45 per day for physician fees. Although the daily charge for ECMO patients is 74.8% higher than for pre-ECMO patients, reflecting the intensive nature of the care and the 24-hour in-house coverage by attending neonatologists during the treatment, the total bill is 1.8% lower. This is attributable to the substantial reduction in length of stay for ECMO patients compared with those treated conventionally. Had the equipment component of program development costs been amortized over 5 years (the conventional approach) instead of 1, the total bill for ECMO patients would have been even lower.

The analysis just described included survivors and nonsurvivors in both groups. When survivors alone are compared in each group, the length of stay and charge differences are even more dramatic. ECMO survivors had an average hospitalization of 25 days compared with pre-ECMO survivors who stayed at CHNMC an average of 75.8 days \( (t = 6.1, p < .0005) \). Table 4 presents the financial information for these infants. The total charge for ECMO survivors was $3,932.80 per day, or $98,320 per episode (25 days), including $2,928.90 per day for hospital charges and $1,003.90 per day for physician fees. The charges for ECMO survivors were almost $75,000 or 43% lower than charges for pre-ECMO survivors.

### Table 1. Clinical Parameters for ECMO and Pre-ECMO Groups

<table>
<thead>
<tr>
<th>Study Group</th>
<th>Gender (M/F)</th>
<th>Mean Gestational Age (wks)</th>
<th>Mean Birth Weight (g)</th>
<th>Average Length of Stay (days)</th>
</tr>
</thead>
<tbody>
<tr>
<td>ECMO</td>
<td>17/8</td>
<td>38.8</td>
<td>3,259</td>
<td>21.0</td>
</tr>
<tr>
<td>Pre-ECMO</td>
<td>11/3</td>
<td>38.9</td>
<td>2,970</td>
<td>37.4*</td>
</tr>
</tbody>
</table>

\*\( p \leq .05 \)

ECMO = extracorporeal membrane oxygenation;
M = male; F = female.

### Table 2. Pre-ECMO and ECMO Groups: Primary Diagnoses

<table>
<thead>
<tr>
<th>Diagnosis</th>
<th>Pre-ECMO (n = 14)</th>
<th>ECMO (n = 25)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Congenital diaphragmatic hernia</td>
<td>3</td>
<td>2</td>
</tr>
<tr>
<td>Meconium aspiration syndrome</td>
<td>7</td>
<td>12</td>
</tr>
<tr>
<td>Pure persistent pulmonary hypertension</td>
<td>0</td>
<td>2</td>
</tr>
<tr>
<td>of the newborn</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Severe hyaline membrane disease of the</td>
<td>2</td>
<td>7</td>
</tr>
<tr>
<td>newborn</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Sepsis</td>
<td>2</td>
<td>2</td>
</tr>
</tbody>
</table>

*All patients had persistent pulmonary hypertension of the newborn as a secondary diagnosis.

ECMO = extracorporeal membrane oxygenation.

### Table 3. Financial Data of ECMO and Pre-ECMO Groups

<table>
<thead>
<tr>
<th>Study Group</th>
<th>Average Length of Stay (Days)</th>
<th>Total Average Daily Charges</th>
<th>Total Average Charges/Patient</th>
</tr>
</thead>
<tbody>
<tr>
<td>ECMO</td>
<td>21.0</td>
<td>$4,371.62</td>
<td>$91,804.02</td>
</tr>
<tr>
<td>Pre-ECMO</td>
<td>37.4*</td>
<td>$2,500.65</td>
<td>$93,524.31</td>
</tr>
</tbody>
</table>

\*\( p \leq .05 \)

ECMO = extracorporeal membrane oxygenation.
Table 4. Financial Data of ECMO and Pre-ECMO Survivors

<table>
<thead>
<tr>
<th>Study Group</th>
<th>Average Length of Stay (days)</th>
<th>Total Average Daily Charges</th>
<th>Total Average Charges per Patient</th>
</tr>
</thead>
<tbody>
<tr>
<td>ECMO survivors</td>
<td>25.0</td>
<td>$3,932.80</td>
<td>$98,320.00</td>
</tr>
<tr>
<td>Pre-ECMO survivors</td>
<td>75.8*</td>
<td>$2,286.05</td>
<td>$173,282.59*</td>
</tr>
</tbody>
</table>

*p < .001.

ECMO = extracorporeal membrane oxygenation.

Discussion

ECMO therapy now is being used in more than 20 major neonatal centers in the United States; additional programs are rapidly being developed. Using historical controls, these centers developed clinical criteria for predicting a population of infants with less than a 20% chance of survival if treated conventionally. All centers have shown significant increases in survival as we have, but to date none has analyzed the financial effect of this intensive therapy. Our analysis has shown that ECMO is both less costly and more effective than the therapy it replaces.

The use of historical controls is well established in cases where previous experience has shown a high mortality with conventional treatment and a substantial improvement with the therapy under study [10]. This is clearly the case with ECMO. Although there are limitations to this approach when compared with a randomized controlled clinical trial, initiating such a trial at this relatively late stage in dissemination of the technology was not considered feasible. The historical control population was the same one used to develop the original entry criteria for ECMO therapy at CHNMC. Infants in both pre-ECMO and ECMO groups, therefore, had identical clinical parameters (see Table 1), and all were well matched on demographic variables. All charges were reviewed by a single researcher [9]. Finally, there were no changes in attending faculty or formal nursery protocol during this period, and thus, we conclude, no major changes in conventional therapy during the study period that would have biased clinical or financial analyses based on the pre-ECMO group.

In the financial analysis, charges were used rather than costs because that is how the information is kept by this hospital and many others. It is recognized that cost data are preferable, but charges for the NICU and ECMO are related to costs in a fairly uniform fashion, so percentage differences between ECMO and conventional therapy would remain whether costs or charges were used. The analysis also was restricted to care at CHNMC. We were unable to obtain precise information on cost of hospital care after discharge from CHNMC because the study period went back to 1982. If we had obtained this information, it would have been very difficult to ensure its comparability with CHNMC financial data. What is clear, however, is that the vast majority of ECMO patients convalesce at home, whereas those receiving conventional therapy remain at CHNMC because of maximal ventilator therapy or are discharged to community hospitals for additional inpatient care. All ECMO infants treated at CHNMC have been free of respiratory disease; none has required readmission. It is not unreasonable to assume, therefore, that follow-up financial data would only lend strength to the results reported here.

Improved survival is gratifying from a clinical standpoint, but it also carries the social and economic advantages inherent in preventing the unnecessary deaths of infants who now can grow up to be productive adults. Quantifying the savings realized (i.e., determining the value of a life) is beyond the scope of this article. ECMO therapy does, however, have another financial advantage that can be calculated: reduced health care expenditures for infants with severe acute lung disease. These reductions stem from decreased length of hospitalization, which has additional benefits such as reduced risk of nosocomial infections or other iatrogenic conditions and less emotional and physical hardship for parents. At CHNMC, charges for ECMO patients were 2% lower than for the pre-ECMO group. Perhaps the most striking finding was that, when only survivors of both groups were compared, ECMO therapy was 43% less costly. Thus, not only are more infants saved, but also the cost per survivor is considerably reduced when comparing ECMO with conventional treatment.

A major concern with any drastic intervention is the morbidity among survivors. In the context of ECMO this includes chronic lung disease (oxygen dependency beyond 1 month of age), neurological abnormality (e.g., spasticity), and severe developmental delay (cognitive and psychomotor). Although it is too soon to predict long-term outcome, the evidence during the first year is encouraging and similar to that reported elsewhere for critically
ill newborns [11,12]. For example, chronic lung disease occurred in approximately 10% of the cases. A similar proportion of survivors had a major intra-
cranial/intraventricular hemorrhage (ICH/IVH). Se-
vere developmental delay is most likely associated 
with the severity of ICH/IVH as in other popula-
tions. On the positive side, 75% of the ECMO sur-
vivors appear to be indistinguishable from healthy 
full-term infants, with normal growth parameters, 
no neurological abnormality or chronic lung dis-
ease, and scores at or above the normal range on 
the Bayley Scales of Infant Development.

This study has not addressed the question of 
costs to the health care system in the larger sense. 
Although reducing costs of care for individual pa-
tients is a step in the right direction, it is a reduction 
in marginal costs, not total average costs. In the 
short run, CHNMC will not experience a reduction 
in utilization of the intensive care nursery as a re-
sult of shorter lengths of stay for ECMO patients, 
especially in a program whose maximum capacity 
is two ECMO bassinets. Instead, additional infants 
will be admitted as bassinets become available 
more quickly. The total costs of running the nur-
sery, therefore, are not likely to decrease. Tech-
niques are now being investigated, however, that 
could expand the population of infants suitable for 
ECMO and at the same time, make it more feasible 
to operate high-volume programs. If this were to 
to occur, the effect on neonatal intensive care nur-
series in the form of decreased use could be suf-
ficient to affect total costs.

Summary

Creating chronic pulmonary problems while treat-
ing acute lung disease has long been a frustration 
for those who work in NICUs. For infants with se-
vere PPHN, ECMO therapy offers an effective alter-
native that is less costly socially as well as econom-
ically.

References

tion of neonatal intensive care of very-low-birth-weight-
2. Budetti P, McManus P, Harrand N, et al. The costs and effec-
tiveness of neonatal intensive care (background paper no. 2, 
case study no. 10). Washington, DC: Office of Technology 
Assessment, 1981
3. Fineberg HV, Hiatt HH. Evaluation of medical practices: the 
301:1086–1091
305:489–494
5. Andrews AF, Roloff DN, Bartlett RH. Use of extracorporeal 
membrane oxygenators in persistent pulmonary hyperten-
poreal membrane oxygenation for newborn respiratory fail-
poreal membrane oxygenation (ECMO) in newborn respira-
tory failure: technical considerations. Trans Am Soc Artif 
Intern Organs 1979;25:173–175
use of an extracorporeal membrane oxygenator in neonatal 
poreal membrane oxygenation (ECMO) in a population of 
infants with persistent pulmonary hypertension of the new-
New York: Oxford University Press, 1980:194
11. Kirkpatrick BV, Krummel TM, Mueller DG, et al. Use of ex-
tracorporeal membrane oxygenation for respiratory failure 
12. Towne BH, Lott IT, Hicks DA, et al. Long-term follow up of 
infants and children treated with extracorporeal membrane 