Neonatal survival during a 2,500-mile flight

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Neonatal respiratory failure, no matter what the cause, may not always respond to standard mechanical ventilation techniques. Extracorporeal membrane oxygenation has emerged over the last 15 years as an adjunct to the treatment of these babies with a greater than 80% survival nationwide.

Limited resources and personnel costs can be prohibitive, forcing regionalization of extracorporeal membrane oxygenation (ECMO) centers. Geographic distance from a center should not limit its potential application, however. Familiarity with the technique, early application of the modality and the availability of medical air transport, allows for referral and transfer of neonates over great distances with excellent results and outcomes.

We present a case of respiratory failure in a neonate transported 2,500 miles for ECMO therapy with an excellent outcome and a rapid return home.

Introduction

Neonatal respiratory failure secondary to meconium aspiration, sepsis, diaphragmatic hernia and respiratory distress syndrome can be successfully treated with extracorporeal membrane oxygenation (ECMO) with an 80% survival and minimal mortality[1-8]. The treatment of neonatal respiratory failure with prolonged veno-arterial extracorporeal oxygenation is a considerable undertaking, however, and requires a significant commitment on the part of those involved, with continuous nursing, technician and physician coverage for what may be many weeks. A consistent demand for such service and a significant population base of potential patients is needed to keep an ECMO team optimally trained, and the required equipment used in order to be cost-effective. Because of these constraints, ECMO centers have become regionalized, with many major metropolitan teaching hospitals now having a 24-hour on-call ECMO team treating two or more neonates a month.

Although it may be possible to document the periodic need for ECMO in various locales, limited resources and personnel make the creation of an ECMO service economically infeasible at many medical centers. The presence of an efficient, on-call, medical air-transport system, especially when dealing with great distances, makes the need for a low-volume, high-cost local ECMO center less critical. Such medical air-transport has been shown to optimize care for neonatal and pediatric patients at regional medical centers, regardless of distance, in a number of disease states, including respiratory failure[9-13].

We present a case of a Hawaii newborn who had progressive respiratory failure and pulmonary hypertension due to severe meconium aspiration, and who was successfully transferred by military medical evacuation aircraft over 2,500 miles from Honolulu to Los Angeles and UCLA Medical Center for ECMO with an excellent outcome.

Case Study

A 3.65 kilogram infant was born by spontaneous vaginal delivery 2 hours after rupture of membranes, to a healthy gravida 1, para 0 woman who had had good prenatal care at 42 weeks' gestation. Delivery was complicated by the cord around the infant's neck, meconium staining of the skin and aspiration of meconium. Oro-tracheal suctioning at delivery revealed small amounts of blood-tinged meconium from below the vocal cords on 4 tries. Apgar scores were 4, 6, and 8 at 1, 3 and 10 minutes respectively. The baby developed progressive cardiopulmonary insufficiency requiring intubation with an FiO_2 of 1.00, pressure settings of 37/9 cm H_2O, and a ventilatory rate of 120/min in order to maintain a pO_2 above 40 torr. Serial chest roentgenograms showed progressive opacification of both lung fields with worsening bilateral air bronchograms. The baby required dopamine and dobutamine infusions to support blood pressure and continuous i.v. fentanyl citrate for sedation.

At this point, the neonatology physicians communicated with the UCLA ECMO team regarding transfer to UCLA Medical Center for evaluation and for ECMO should the baby's condition continue to deteriorate. Intracranial hemorrhage and cardiac structural abnormalities were ruled out by ultrasound study in Hawaii prior to transport. Arrangements were made for air evacuation to Los Angeles by military air ambulance. The infant was accompanied by a neonatologist and a medical flight nurse in accordance with American Academy of Pediatrics guidelines[14].

The patient arrived in Los Angeles at 37 hours of age after a 6-hour flight. At that time she weighed 4.18 kg, a 0.53 kg (15%) increase in weight as a result of vigorous fluid resuscitation necessary to maintain reasonable cardiopulmonary perfusion parameters. Dopamine (15 mcg/kg/min) and dobutamine (17 mcg/kg/min) were required to maintain a systolic blood pressure of 65 and a heart rate of 120 beats per minute. Arterial blood gas on ventilator settings of FiO_2 -1.00, rate 80/min and pressures of 34/4 cm H_2O resulted in a pH of 7.52, pCO_2 31 torr and pO_2 49 torr.

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The oxygenation index (OI) was calculated at 0.41 and the alveolar-arterial oxygen difference ($AaDO_2$) was 633 torr. However, conservative medical management was not successful in reversing the pulmonary hypertension and respiratory failure. Therefore, the patient was placed on ECMO at 57 hours of life. After initiation of ECMO, ventilator settings were immediately reduced to FiO_2 - 0.30, rate 15/min and pressures of 24/14 cm H_2O. Blood gas results showed an arterial oxygen saturation of 99 to 100% with a mixed venous saturation of 80%, documenting good oxygen delivery and normal peripheral tissue oxygen extraction. ECMO flows approximating 80% partial cardiopulmonary bypass were maintained for 24 hours; then the infant was rapidly weaned as she demonstrated decreasing pulmonary hypertension and improving pulmonary function at ventilator settings while at rest. The infant was removed from ECMO support after 66 hours, gradually weaned off the ventilator over the next 72 hours and then extubated.

On day 21 of life, the infant and her parents returned to Hawaii via commercial air transport and without incident. The infant continued to do well on local follow-up in Hawaii 2 years later.

Discussion

The treatment of respiratory failure with partial cardiopulmonary bypass or Extracorporeal Membrane Oxygenation originated at the University of California, Irvine, under Robert Bartlett MD and associates in the early 1970s. Initial trials of ECMO took place on severely ill patients with unresponsive respiratory failure in all age groups from premature neonates to adults. The early studies showed a survival advantage only in newborns near parturition. However, premature infants had a high incidence of intracranial hemorrhage while on systemic anticoagulation. Adults showed no improvement in survival when ECMO was applied instead of standard mechanical ventilatory management at that time.

The indications and contraindications for ECMO (Table 1) were derived from the early experience of Bartlett and others who began using ECMO to treat neonatal respiratory failure unresponsive to aggressive mechanical ventilatory support. These criteria attempt to define the population of neonates who have reversible causes of pulmonary hypertension and respiratory failure[15]. This does not include those neonates in whom ECMO might function as temporizing therapy, such as being a bridge to cardiac transplant, or a cardiac reconstructive procedure, or for those in the pediatric age group who might benefit from ECMO therapy (near-drowning, pneumonia, etc). Current studies are attempting to determine the applicability and efficacy of ECMO in those populations.

Overall survival of neonates on ECMO, including the various causes of neonatal pulmonary hypertension and respiratory failure as reported in the National Neonatal ECMO Registry, are listed in Table 2. Cumulative survival of the 3,500 neonates treated since 1972 is 85%[1]. These statistics are more impressive when it is noted that criteria for ECMO therapy was based on parameters calculated to define a predicted 80% mortality with conventional mechanical ventilator management.

The criteria used at UCLA are similar to those used across the nation at other centers (Table 3), although it should be noted that variability in the criteria exists among ECMO centers, based on their individual experiences[15]. It is also important to note that these are entry criteria for placing an infant on ECMO and are not criteria for transport to an ECMO center for the purpose of evaluation.

Most centers report that the majority of ECMO candidates are transferred from other institutions to the center, an experience supported at UCLA where 94% of patients treated were transferred from other hospitals.

The average age of neonates placed on ECMO at UCLA was 56±36 hours, approximately 20 hours after admission to the Neonatal Intensive Care Unit. Although the usual en route transport time to UCLA from the referring hospitals for these infants averaged less than 2 hours, many of the referral calls were actually initiated 12 to 24 hours prior to the actual transport of the patients. The time between consideration of ECMO at the transferring institution, acceptance of the referral call by the tertiary Neonatal Intensive Care facility and the actual arrival of the patient at UCLA was in some cases as long as 24 hours and within a 150-mile radius from UCLA Medical Center. Because of the short distances involved, this delay did not complicate initiation of ECMO treatment in most cases; however, longer, out-of-state transport with travel times more than 5 to 6 hours might have been more difficult.

The evidence from literature supports early transport of acutely ill neonatal and pediatric patients to a regional neonatal intensive care unit after stabilization as the ideal; such a system maximizes survival in a variety of disease states[9,16-17]. This also has been shown to be true in the adult age group[18-19].

It is impossible to predict at what rate an infant with pulmo-

Table 1. Criteria for treatment of neonates with ECMO.

1. gestational age > 35 weeks
2. weight > 2 kilograms
3. no structural cardiac disease
4. no intracranial hemorrhage
5. no severe coagulopathy
6. < seven days of assisted ventilation (relative limit)

or < 10 days assisted ventilation (absolute limit)

7. maximal ventilator management
6. respiratory failure criteria (defined at each institution)

Table 2. National ECMO Registry Center pooled survival data.

PATHOLOGY	NO. PATIENTS	SURVIVAL %
Meconium aspiration	1313	92.5
RDS	517	83.2
Diaphragmatic hernia	546	62.5
Pneumonia/sepsis	366	76.8
Air leak syndrome	10	60.0
Cardiac	46	60.9
Persistent fetal circulation	456	86.8
Other	81	84.0

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Table 3. ECMO respiratory failure criteria as defined at UCLA.

RESPIRATORY FAILURE CRITERIA AS DEFINED AT UCLA
Alveolar arterial oxygen difference ($AaDO_2$)
= barometric pressure - water vapor pressure (47 mm Hg) - (pO_2 + pCO_2)
= (760 mm Hg) - (47 mm Hg) - (pO_2 + pCO_2)

Oxygenation index (OI)
= FiO_2 x pO_2 divided by mean airway pressure

CALCULATIONS PREDICTIVE OF A >80% MORTALITY[3]
$AaDO_2$
>610 mm Hg for 8 hours,
or >605 mm Hg with a PIP >38 cm H_2O for 4 hours

Oxygenation index. (OI) >0.4

nary hypertension and respiratory failure will deteriorate. However, the success treatment with ECMO is as much affected by early referral and expedient transport before the baby actually meets ECMO criteria as it is by reason of the severity of the respiratory failure. The neonate we report tolerated ECMO therapy without complication, survived her respiratory insult and did extremely well in follow-up in great part because of early aggressive therapy and early transport by the neonatology service in Hawaii, *before* the need for ECMO was clearly defined.

A regional ECMO Center in Hawaii would obviate the need for long-distance transport, but it would require a significant start-up cost (estimated at $250,000) and would require physician, technician and nursing bedside support continuously for the entire (average 120 hours) ECMO therapy duration. In addition, it has been recommended that such centers treat a minimum of 2 to 3 neonates per month in order to maintain the competence and certification of the ECMO personnel, and in order to justify the costs of running and maintaining an ECMO program. Currently the need for ECMO in the State of Hawaii may not justify the creation of a regional ECMO referral center; however, as the health care system in the Pacific Basin develops, with Hawaii in a geographically centralized position, this need may change and a Hawaii Regional ECMO Referral Center may become necessary. Until that time comes, it can be shown that long-distance transport of severely ill neonates with pulmonary hypertension and respiratory failure is feasible using currently available transport systems. Excellent patient outcomes are expected, given early referral and aggressive stabilization pre-flight.

REFERENCES

1. Extracorporeal Life Support Organization (ELSO). *Registry Data.* Jan 1990.
2. Bartlett RH, Andrews AF, Toomasian JM, Haiduc NJ, Gazzaniga AB. Extracorporeal membrane oxygenation for newborn respiratory failure: 45 cases. *Surgery.* 1982;92:425-433.
3. Krummel TM, Greenfield LJ, Kirkpatrick BV, Mueller DG, Ormazabal M, Salzberg AM. Clinical use of an extracorporeal membrane oxygenator in neonatal pulmonary failure. *J Pediatr Surg.* 1982;17:525-531.
4. Bartlett RH, Roloff DW, Cornell RG, Andrews AF, Dillon PW, Zwischenberger JB. Extracorporeal membrane oxygenation in neonatal respiratory failure: a prospective randomized trial. *Pediatrics.* 1985;76:479-487.
5. Bartlett RH, Gazzaniga AB, Toomasian J, et al. Extracorporeal membrane oxygenation (ECMO) in neonatal respiratory failure; 100 cases. *Ann Surg.* 1986;204:236-245.
6. Short BL, Miller MR, Anderson KD. Extracorporeal membrane oxygenation in the management of respiratory failure in the newborn. *Clin Perinatol.* 1987;14:737-748.
7. O'Rourke PP, Crone RK, Vacanti JP, et al. Extracorporeal membrane oxygenation and conventional medical therapy in neonates with persistent pulmonary hypertension of the newborn: a prospective randomized study. *Pediatrics.* 1989;84:957-963.

Table 4. Southern California Regional ECMO Centers and contacts.

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8. Moront MG, Katz NM, Keszler M, et al. Extracorporeal membrane oxygenation for neonatal respiratory failure. A report of 50 cases. *J Thorac Cardiovasc Surg.* 1989;97:706-714.
9. Black RE, Mayer T, Walker ML, Christison EL, Johnson DG, Matlak ME, Storrs B, Clark P. Special report. Air transport of pediatric emergency cases. *N Engl J Med.* Dec 21982;307(23):1465-1468.
10. Arp LJ, Dillon RE, Long MT, Boatwright CL. An emergency air-ground transport system for newborn infants with respiratory distress syndrome. *J Med Assoc State Ala.* Jun 1969;38(12):1112-1117.
11. Arp LJ, Dillon RE, Long MT, Boatwright CL. A transport system for newborns with respiratory distress syndrome. *J Miss State Med Assoc.* Sep 1969;10(9):412-416.
12. Arp LJ, Dillon RE, Long MT, Boatwright CL. An emergency air-ground system for newborn infants with emergency distress syndrome. *Mich Med* Jun 1969;68(11):571-574.
13. Arp LJ, Dillon RE, Long MT, Boatwright CL. An emergency air-ground transport system for newborn infants with respiratory distress syndrome. *Pa Med.* May 1969;72(5):74-76.
14. American Academy of Pediatrics Committee on Hospital Care: Guidelines for Air and Ground Transportation of Pediatric Patients. *Pediatrics.* Nov 1986;78(5):943-950.
15. Beck R, Anderson KD, Pearson GD, Cronin J, Miller MK, Short BL. Criteria for extracorporeal membrane oxygenation in a population of infants with persistent pulmonary hypertension of the newborn. *J Ped Surg.* 1986;21:297-302.
16. Pettett G, Merenstein GB, Battaglia FC, Butterfield LJ, Efird R. An analysis of air transport results in the sick newborn infant: Part 1. The transport team. *Pediatrics.* Jun 1975;55(6):774-782.
17. Merenstein GB, Pettett G, Woodall J, Hill JM. An analysis of air transport results in the sick newborn 11. Antenatal and neonatal referrals. *Am J Obstet Gynecol.* Jul 1 1977;128(5):520-525.
18. Byrd RB, Berns JR, McElvain WH. Air transport of patients in respiratory failure. *Aerosp Med.* Aug 1970;41(8):934-937.
19. Harless KW, Morris AH, Cengiz M, Holt R, Schmidt CD. Civilian ground and air transport of adults with acute respiratory failure. *JAMA.* Jul 28 1978;240(4):361-365.

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[Hawaii takes pride in its graduate, Scott Bjerke, and in the Armed Forces adjunctive assistance/Ed]

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CORONARY ATHERECTOMY

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L. Evidence implicating nonmuscle myosin in restenosis. Use of *in situ* hybridization to analyze human vascular lesions obtained by directional atherectomy. *Circulation.* 1992;85:543 to 553.
14. Buchbinder M, Leon M, Warth D, Marco J, Dorros G, Zacca N, Erbel R. Multi-center registry of percutaneous coronary rotational ablation using the Rotablator (abstract). *J Am Coll Cardiol.* 1992;19:333A.
15. Leon MB, Kent KM, Pichard AD, Spring D, Zacca N, Buchbinder M. Percutaneous transluminal coronary rotational angioplasty of calcified lesions (abstract). *Circulation.* 1991;84:II-521.
16. Basnight MA, Zipkin RE, Sterzler SH, Rosenblum J, Shaw RE, Ward K, Murphy MC, Myler RK. Myocardial injury following coronary rotational ablation: mechanisms and incidence (abstract). *J Am Coll Cardiol.* 1992;19:334A.
17. Sketch MH, O'Neill WW, Galichia JP, Feldman RC, Walker CM, Sawchak SR, Meany TB, Wall TC, O'Connor CM, Tcheng JE, Philips HR, Stack RS. Restenosis following coronary extraction-endarterectomy: the final analysis of a multicenter registry (abstract). *J Am Coll Cardiol.* 1992;19:277A.
18. Kramer B, Larkin T, Niemyski P, Parker M. Coronary atherectomy in acute ischemic syndromes: implications of thrombus on treatment outcome (abstract). *J Am Coll Cardiol.* 1991:17:385A.
19. Leon MB, Pichard AD, Kramer B, Knopf W, O'Neill W, Stack R. Efficacious and safe transluminal extraction atherectomy in patients with unfavorable coronary lesions (abstract). *J Am Coll Cardiol.* 1991;17:219A.
20. Cook SL, Eigler NL, Shefer A, Goldenberg T, Forrester JS, Litvack F. Percutaneous excimer laser coronary angioplasty for lesions not ideal for balloon angioplasty. *Circulation.* 1991;84:632 to 643.
21. Savage M, Fischman, Leon M, Ellis S, Schatz R, Goldberg S. Restenosis risk of single Palmaz-Schatz stents in native coronaries: Report from the core angiographic laboratory (abstract). *J Am Coll Cardiol.* 1992;19:277A.
22. Naftilan AJ. Chemical atherectomy: A novel approach to restenosis. *Circulation.* 1991;84:945 to 947.

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"You don't need to worry 'bout Daddy and me ... we're living in a hotel now that the Health Inspector came and padlocked the house."