PAPER

Extracorporeal Membrane Oxygenation for Nonneonatal Acute Respiratory Failure

The Massachusetts General Hospital Experience From 1990 to 2008

Deepika Nehra, MD; Allan M. Goldstein, MD; Daniel P. Doody, MD; Daniel P. Ryan, MD; Yuchiao Chang, PhD; Peter T. Masiakos, MD

Objective: To determine the efficacy of extracorporeal membrane oxygenation (ECMO) for nonneonatal acute respiratory failure.

Design: Single-institution, retrospective medical record review from February 1990 to March 2008.

Setting: Tertiary care hospital.

Patients: Eighty-one nonneonatal patients (mean age, 23 years; age range, 2 months to 61 years) with acute respiratory failure who had failed maximal ventilator support received ECMO therapy between 1990 and 2008. Patients were grouped into 6 categories based on diagnosis: sepsis (n=8), bacterial or fungal pneumonia (n=15), viral pneumonia (n=9), trauma or burn (n=10), immunocompromise (n=15), and other (n=24).

Main Outcome Measure: Survival to hospital discharge.

Results: Overall survival was 53%. Survival was highest in patients with viral pneumonia (78%), followed by bacterial pneumonia (53%), sepsis syndrome (44%), and immunocompromise (40%). Patients treated following trauma or burns had the lowest survival (33%). The average age was 19 years for survivors as compared with 27 years for nonsurvivors. Survival was lower in patients with multiple organ failure as compared with those with single organ failure (33% vs 60%, respectively), in patients who experienced mechanical ventilation for longer than 10 days prior to the initiation of ECMO as compared with those who received ventilatory support for less than 10 days prior to the initiation of ECMO (31% vs 57%, respectively), and in patients requiring more than 400 hours of ECMO support as compared with those requiring less than 400 hours of ECMO support (42% vs 55%, respectively).

Conclusions: Therapy with ECMO may provide a survival benefit in carefully selected patients with nonneonatal acute respiratory failure who have failed maximal ventilator support. Nonneonatal survival with ECMO therapy is strongly dependent on diagnosis, with the highest survival seen in those with viral or bacterial pneumonia. Older age, multiple organ failure, prolonged ventilation prior to ECMO initiation, and long ECMO runs are associated with decreased survival.

Arch Surg. 2009;144(5):427-432

Severe acute respiratory failure (ARF), which includes both acute lung injury and acute respiratory distress syndrome (ARDS), is characterized by a profound deterioration in oxygenation and/or ventilation despite maximal supportive respiratory therapy.[1] Although ARF is a relatively infrequent occurrence in nonneonatal patients, with an estimated incidence of 78.9 per 100 000 person-years,[2] it often results in devastating consequences. Paramount in the care of patients with ARF is the use of mechanical ventilatory strategies that are carefully designed to improve gas exchange without exacerbating the underlying lung injury. In the last few years attempts have been made to optimize lung-protective ventilation,[3-5] but despite these advances reported mortality for patients with severe ARDS remains as high as 66%.[2,6]

See Invited Critique at end of article

Some patients with severe ARF require strategies beyond conventional mechanical ventilation to prevent additional lung injury, life-threatening hypoxemia, and death. Extracorporeal membrane oxygenation (ECMO), first introduced clinically in 1972, has been applied as a means of cardiopulmonary support for patients with potentially reversible cardiac and/or respiratory failure in whom maximal conventional ventilatory

Author Affiliations: Divisions of Pediatric Surgery (Drs Nehra, Goldstein, Doody, Ryan, and Masiakos) and General Medicine (Dr Chang), Massachusetts General Hospital, Boston.

©2009 American Medical Association. All rights reserved.
Downloaded From: http://archsurg.jamanetwork.com/ on 04/26/2017

Table. Patient Characteristics, Arterial Blood Gas Values, and Laboratory Values

Variable	Mean (SEM) Survivors (n=42)	Mean (SEM) Nonsurvivors (n=39)	*P* Value
Age, y	19 (2.6)	27 (2.8)	.05
Time on ECMO, h	260 (37.3)	289 (37.7)	.58
Pre-ECMO ventilation			
Ventilatory support, d	5.4 (0.7)	8.0 (0.9)	.21
FIO_2 >0.90, h	24.3 (5.6)	48.6 (21.0)	.72
PIP >40 cm H_2O, h	21.2 (5.2)	91.6 (28.0)	.006
PEEP >8 cm H_2O, h	59.8 (12.3)	140.8 (29.7)	.03
Pre-ECMO arterial blood gas values			
pH	7.31 (0.01)	7.29 (0.05)	.16
PaO_2, mm Hg	69.4 (9.3)	57.6 (4.6)	.22
$PaCO_2$, mm Hg	60.0 (3.3)	65.5 (4.5)	.69
PaO_2/FIO_2 ratio	75.5 (10.8)	58.9 (4.9)	.18
Laboratory values			
Pre-ECMO PRBC transfusions, U	2.7 (0.6)	9.1 (1.9)	.001
PRBC transfusions during ECMO, U	18.3 (3.2)	33.6 (4.8)	.01
Pre-ECMO WBC count, /μL	18 300 (1700)	19 000 (2200)	.92
Pre-ECMO hematocrit, %	33.2 (0.8)	31.8 (0.8)	.37
Pre-ECMO platelet count, $\times 10^3$/μL	247 (25)	196 (29)	.02
Pre-ECMO serum creatinine, mg/dL	0.72 (0.09)	1.53 (0.20)	<.001

Abbreviations: ECMO, extracorporeal membrane oxygenation; FIO_2, fraction of inspired oxygen; $PaCO_2$, partial pressure of carbon dioxide; PaO_2, partial pressure of oxygen, arterial; PEEP, positive end-expiratory pressure; PIP, peak inspiratory pressure; PRBC, packed red blood cell; WBC, white blood cell.

SI conversion factors: To convert WBC count to $\times 10^9$ per liter, multiply by .001; platelet count to $\times 10^9$ per liter, multiply by 1.0; and serum creatinine to micromoles per liter, multiply by 88.4.

strategies have been exhausted.[7] Most commonly, ECMO is used as an alternative means of ventilatory support for neonates who have failed maximal mechanical ventilation,[8,9] but it is also considered by many to be helpful in selected nonneonatal patients.[10-12] Significant controversy surrounds the use of ECMO in the nonneonatal population. Although multiple retrospective and noncontrolled prospective studies report a survival advantage for patients with severe ARF when ECMO is used,[13,14] the 2 randomized controlled studies[15,16] conducted to date failed to demonstrate an improved outcome with ECMO support. The purpose of this study is to report our ECMO experience in nonneonatal patients with severe ARF. Our data document improved survival in patients with seemingly irreversible ARDS in whom all known ventilation strategies have failed and support the use of ECMO in severe ARF while highlighting the importance of careful patient selection.

METHODS

After appropriate institutional review board approval was obtained, a retrospective review of all records from the pediatric surgical service ECMO database at the Massachusetts General Hospital was performed. Eighty-one nonneonatal patients aged 2 months to 61 years who were treated with venoarterial or venovenous extracorporeal lung support between February 1990 and March 2008 were identified.

All of the patients with refractory ARF who received ECMO had failed maximal ventilator and medical therapy. The medical teams caring for these patients felt that the patients would not survive without ECMO, and all of the patients had ratios of partial pressure of oxygen, arterial (PaO_2) to fraction of inspired oxygen (FIO_2) ratios near 60. Additionally, all members of the team felt that the patients had a reasonable chance of survival if the respiratory illness could be supported. Therapy with ECMO was considered only after all septic foci had been drained, pulmonary air leaks managed with thoracostomy tubes, and all identified infections treated with appropriate antibiotic therapy. Specific exclusion criteria included an irreversible underlying pulmonary injury and ongoing bleeding or the coexistence of any condition that would prevent systemic anticoagulation.

Ventilator management while receiving ECMO was directed at limiting airway pressures by maintaining peak inspiratory pressure (PIP) of less than 30 cm H_2O and positive end-expiratory pressure (PEEP) between 20 and 24 cm H_2O. Large air leaks were treated with no PEEP and minimal ventilation until they resolved. Anticoagulation maintained activated clotting times at a mean (SD) of 180 (20) seconds for all of the patients.

The patients were divided into 2 groups: survivors (n=42) and nonsurvivors (n=39). Patients were grouped into 6 categories based on diagnosis: sepsis syndrome (n=8), bacterial or fungal pneumonia (n=15), viral pneumonia (n=9), trauma or burn (n=10), immunocompromise (n=15), and other (n=24). The detailed characteristics for these patients including age, duration of ECMO therapy, ventilatory support variables before ECMO therapy, and laboratory values are shown in the **Table**.

The primary outcome measure was patient survival to hospital discharge. Wilcoxon tests were used to compare continuous variables between survivors and nonsurvivors, whereas Pearson χ^2 exact tests were used for categorical variables. Variables with $P<.10$ from the univariate analysis were considered as candidates for the multiple logistic regression analysis. Independent predictors for survivors were identified as those with $P<.05$ from the multiple logistic regression model.

RESULTS

Eighty-one nonneonatal patients received ECMO support at the Massachusetts General Hospital between 1990

©2009 American Medical Association. All rights reserved.
Downloaded From: http://archsurg.jamanetwork.com/ on 04/26/2017

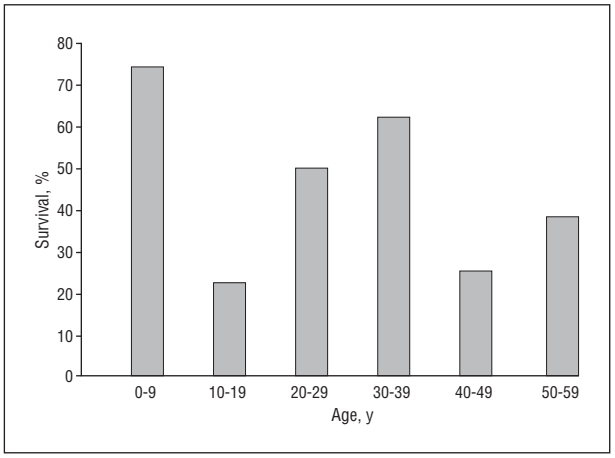

Figure 1. Survival by age.

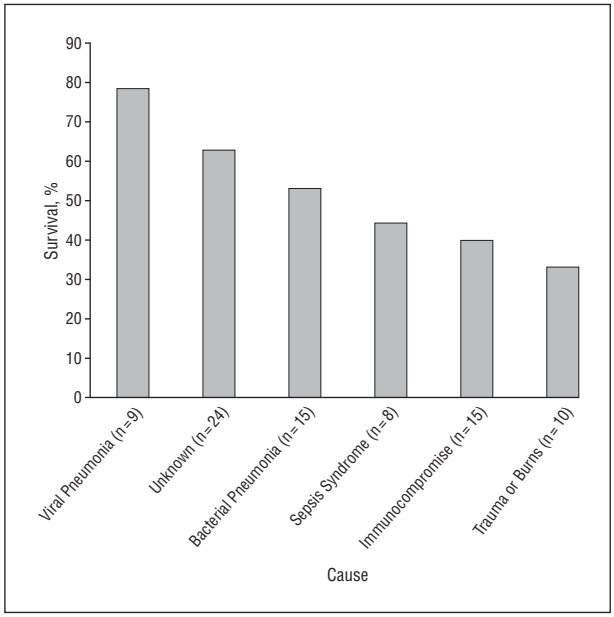

Figure 2. Survival by cause of acute respiratory failure.

and 2008. Of these 81 patients, 42 (52%) survived and were discharged from the hospital. The detailed characteristics for these patients are shown in the Table. There was no significant difference in survival between venovenous and venoarterial ECMO therapy groups (56% vs 46%, respectively; $P=.24$). The mean age for the sample as a whole was 23 years (age range, 2 months to 61 years). The mean age of the survivors was 19 years (range, 2 months to 56 years) compared with a mean age of 27 years (range, 4 months to 61 years) for the nonsurvivors. A nonlinear distribution was observed when patient age was plotted against rate of survival (**Figure 1**), with the highest survival seen in the age group of 0 to 9 years (74%), followed by the age group of 30 to 39 years (62%).

The average duration of ECMO support was 274 hours (range, 1-1154 hours). This was comparable between the 2 groups, with an average duration of 260 hours (range, 1-1154 hours) for survivors and 289 hours (range, 1-935 hours) for nonsurvivors. Survival decreased as the duration of ECMO support lengthened, with an average survival of 58% for those receiving ECMO support for 0 to 200 hours, which decreased to 47% for those supported for 200 to 400 hours and 42% for those supported for longer than 400 hours.

The average duration of mechanical ventilation prior to ECMO support was 6.6 days (range, <1-41 days). The average duration was 5.4 days (range, <1-19 days) for survivors and 8.0 days (range, <1-41 days) for nonsurvivors. Patients who received ventilatory support for less than 10 days prior to the initiation of ECMO were more likely to survive to hospital discharge than those ventilated for longer than 10 days prior to ECMO initiation (57% vs 31%, respectively; $P=.12$). With regard to other pre-ECMO ventilation factors, nonsurvivors as compared with survivors spent more time with an FIO_2 greater than 0.90 (48.6 vs 24.3 hours, respectively; $P=.72$), a PIP greater than 40 cm H_2O (91.6 vs 21.2 hours, respectively; $P=.006$), and a PEEP greater than 8 cm H_2O (140.8 vs 59.8 hours, respectively; $P=.03$).

There were no significant differences between survivors and nonsurvivors in any pre-ECMO arterial blood gas values or in the PaO_2/FIO_2 ratio. Survivors as compared with nonsurvivors received fewer packed red blood cell (PRBC) transfusions prior to ECMO (2.7 vs 9.1 U, respectively; $P=.001$) and during ECMO (18.3 vs 33.6 U, respectively; $P=.01$) and had a lower mean serum creatinine level prior to ECMO (0.72 vs 1.53 mg/dL, respectively [to convert to micromoles per liter, multiply by 88.4]; $P<.001$).

Patients were grouped into 6 categories based on diagnosis: sepsis syndrome (n=8), bacterial or fungal pneumonia (n=15), viral pneumonia (n=9), trauma or burns (n=10), immunocompromise (n=15), and other (n=24). As shown in **Figure 2**, survival was highest in patients with viral pneumonia (78%), followed by bacterial pneumonia (53%), sepsis syndrome (44%), and immunocompromise (40%). Patients treated following trauma or burns had the lowest survival (33%).

Survival was lower in patients with multiple organ failure when compared with those with single organ (respiratory) failure at the time of ECMO initiation (33% vs 60%, respectively; $P=.10$). The nonsurvivors as compared with survivors had a higher complication rate during ECMO (65% vs 35%, respectively; $P<.001$). The most common complications included bleeding (cannulation site, oropharynx, hemothorax, abdominal, intracranial), pneumothorax, pneumomediastinum, renal failure, and cardiac arrest.

In a multiple logistic regression model, age, number of PRBC transfusions prior to ECMO, and number of organ failures were identified as independent predictors of survival. When compared with those aged 40 years and older, the odds ratios of survival were 6.6 for those aged 0 to 9 years, 2.8 for those aged 20 to 39 years, and 0.6 for those aged 10 to 19 years. The odds ratio of survival was 4.5-fold higher for those with PRBC transfusions of 6.5 U or less prior to ECMO and 4.4-fold higher among those without multiple organ failure.

There was an increase in patient survival as the experience with nonneonatal ECMO progressed. The overall survival for patients treated with ECMO between January 2005 and March 2008 was 69% compared with an

©2009 American Medical Association. All rights reserved.
Downloaded From: http://archsurg.jamanetwork.com/ on 04/26/2017

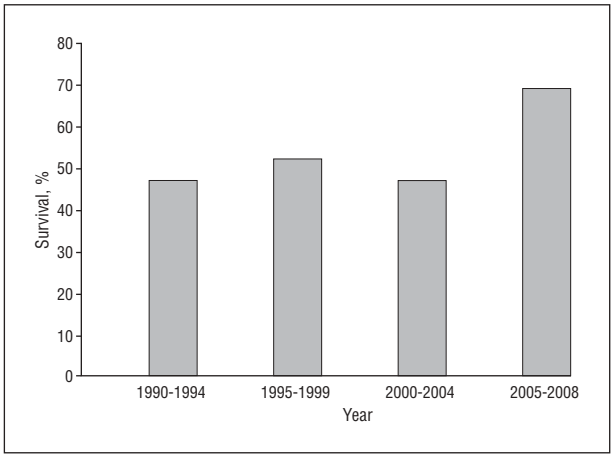

Figure 3. Survival by year of extracorporeal membrane oxygenation therapy.

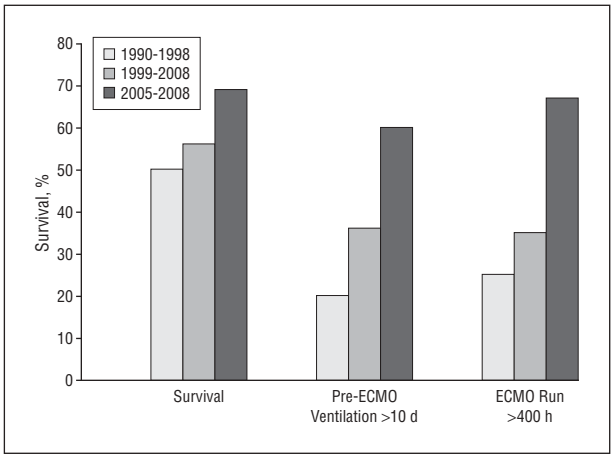

Figure 4. Improvement in survival over time. ECMO indicates extracorporeal membrane oxygenation.

average survival of 50% for those treated with ECMO between February 1990 and December 2004 ($P=.17$) (**Figure 3**). Survival in patients ventilated for longer than 10 days prior to ECMO therapy also improved (67% for 2005-2008 vs 21% for 1990-2004; $P=.12$) as did survival of those requiring ECMO support for longer than 400 hours (67% for 2005-2008 vs 31% for 1990-2004; $P=.32$) (**Figure 4**).

COMMENT

Respiratory insufficiency in nonneonatal patients is usually self-limiting. However, in some cases ARF may progress to fulminant respiratory failure, which is unresponsive to maximal ventilatory support. Advances in mechanical ventilation and the application of gentle ventilation strategies that are designed to promote optimal ventilation and perfusion while sparing the lung parenchyma from trauma have been shown to improve outcomes in many patients with ARF. However, mortality for patients with severe ARF remains as high as 66%.[2,6] Despite our best efforts to prevent irreversible parenchymal injury by incorporating these ventilation strategies into the patient care paradigm, a subset of patients continue to have progressive lung injury that occurs from the underlying disease or from prolonged positive-pressure mechanical ventilation. These patients may benefit from ECMO support.

Notwithstanding the documented success of neonatal ECMO for ARF, there remains significant controversy over the application of ECMO to the nonneonatal population. This is likely owing to the disappointing results reported in past prospective randomized studies.[15,16] However, a number of recent retrospective, uncontrolled prospective studies and anecdotal reports have reported successful lung recovery in this population when ECMO was used. Specifically, several groups have reported survival rates approaching 50% for nonneonatal patients treated with ECMO for severe ARDS in whom all ventilation strategies had been exhausted and mortality approached 100%.[10-12] These data have led to a continued interest in the expanded use of ECMO in nonneonatal patients with severe but presumably reversible ARF who are unlikely to survive with continued mechanical ventilation.

We report our institutional experience with ECMO applied to the nonneonatal population with ARF in an attempt to identify a subset of patients who experience the greatest survival advantage with ECMO support. This may help provide further direction to the use of ECMO in patients with severe ARF.

For 18 years at the Massachusetts General Hospital, ECMO has been used as a therapy of last resort for patients with fulminant ARF. Over the past 10 years and despite application of newer ventilation strategies that have improved survival of patients with severe ARDS, the number of nonneonatal patients who have been treated with ECMO at our institution has nearly tripled. In this period, overall survival of nonneonatal patients treated with ECMO support has improved. We have noted an overall improvement in survival from 50% in 1990 to 2004 to 69% in 2005 to 2008. Additionally, we report improved survival in those subgroups who tended to do poorly in the past, including patients who were ventilated for longer than 10 days prior to ECMO initiation and those with longer ECMO runs (>400 hours). Careful selection of patients who have failed conventional ventilator therapy and the application of ECMO earlier in the disease process have likely affected outcome.

It is important to limit lung injury both before and during ECMO support to maximize the chance of recovery. Identifying patients sooner in the course of their reversible ARF is thought to minimize pre-ECMO ventilator-associated lung injury and to improve survival. Previous studies have indicated that pre-ECMO ventilation exceeding 5 days is a poor prognostic factor.[17] In our experience, survival did not decrease significantly until pre-ECMO ventilation exceeded 10 days. Interestingly, survival in the subset of patients ventilated for longer than 10 days prior to the initiation of ECMO support has markedly increased in the past few years from 21% in 1990 to 2004 to 67% in 2005 to 2008. This may be a reflection of the reduced ventilator-associated lung injury with currently accepted advanced ventilation strategies.

As we have reported in the past,[11] patients with certain disease states have higher rates of survival with ECMO support than others. Survival rates in patients present-

©2009 American Medical Association. All rights reserved.
Downloaded From: http://archsurg.jamanetwork.com/ on 04/26/2017

ing with isolated viral pneumonia or ARF without identifiable cause (likely viral) were 78% and 63%, respectively. In contrast, survival was poor in patients with trauma (33%) and in those who are immunocompromised secondary to chemotherapy or organ transplant (40%). Similarly, poor outcomes were seen in those with multiple organ failure (33%) at the time of ECMO initiation regardless of the underlying cause of the ARF, and multiple organ failure was identified as an independent predictor of poor survival. These data corroborate our reported result from a decade ago in 34 patients that the cause of ARF may have a significant effect on survival following ECMO therapy.[11] Although the cause of ARF cannot be altered, initiating ECMO support earlier especially in the groups with lessened survival may help to improve outcome by limiting damage to the lung parenchyma by mechanical ventilation and preventing the development of multiple organ failure.

Survival with ECMO generally tends to decrease with patient age. We continue to see a bimodal distribution of survival with respect to patient age, with the highest survival seen in the groups aged 0 to 9 years and 30 to 39 years. This distribution was noted previously and has been confirmed with data from the Extracorporeal Life Support Organization database.[11] Although the specific reason for this distribution cannot be identified with certainty, we hypothesize that this is most likely a reflection of the disease processes that affect these age groups rather than an inherent characteristic of the age alone.

Other factors that portend an improved survival with ECMO support include few PRBC transfusions prior to and during ECMO and a higher platelet count prior to the initiation of ECMO. The number of PRBC transfusions prior to the initiation of ECMO was found to be an independent predictor of survival. The patient's risk of bleeding with systemic anticoagulation should be carefully assessed as survival is markedly decreased in those who have hemorrhagic complications during ECMO support.

In 1979, Zapol et al[15] demonstrated no survival advantage of ECMO over conventional ventilatory strategies for severe ARDS. In this study, both the control group and the treatment group had very high mortality rates (91% in the control group vs 90% in the group receiving ECMO). Since that report, most proponents of nonneonatal ECMO have come to realize that that study's results failed to account for the differences between neonatal and nonneonatal lungs with respect to resilience and likely underestimated the time needed to regain lost lung function as the ECMO runs were of short duration (<5 days) and may not have allowed sufficient time for the underlying lung parenchyma to heal. Furthermore, lung-protective ventilatory strategies that are used today were not used in 1979. In that original study, patients experienced prolonged mechanical ventilation prior to the initiation of ECMO and this ventilator strategy continued during ECMO therapy, likely adding ventilator injury to the already damaged lung.

It is clear from the data presented in this article that the time required for lung parenchyma to recover is dynamic and dependent on the individual patient and his or her underlying cause of ARDS. Specifically, the average cannulation time over the study period was 11.4 days (range, <1-48 days). There was no difference in the mean cannulation time between the survivors and the nonsurvivors, and survival was significantly decreased when the ECMO duration exceeded 16.7 days. Still, many of the survivors had courses of ECMO therapy that exceeded 16.7 days, indicating that the decision for duration of the ECMO run should be carefully made on a case-by-case basis as the clinician determines whether there is evidence of improvement in the underlying lung function.

CONCLUSIONS

Therapy with ECMO improves survival in carefully selected patients with nonneonatal ARF who have failed maximal ventilator support. An overall survival of 53% is a marked improvement over the close to 100% mortality that these patients face when ECMO is initiated. Outcome is strongly dependent on diagnosis, with the highest survival seen in those with viral or bacterial pneumonia. Older age, multiple organ failure, prolonged ventilation prior to ECMO initiation, and long ECMO runs are associated with decreased survival.

We believe this article supports the use of ECMO therapy in those patients with severe ARDS who have failing ventilator support. We are hoping to better determine indicators of therapy, particularly in those with lessened survival. Perhaps initiation of ECMO therapy earlier in the treatment of ARDS in those specific groups may be beneficial.

Accepted for Publication: January 2, 2009.
Correspondence: Peter T. Masiakos, MD, Division of Pediatric Surgery, Massachusetts General Hospital, WRN 11, 55 Fruit St, Boston, MA 02114 (pmasiakos@partners.org).
Author Contributions: Dr Nehra had full access to all of the data in the study and takes responsibility for the integrity of the data and the accuracy of the data analysis. *Study concept and design:* Nehra, Doody, Ryan, and Masiakos. *Acquisition of data:* Nehra and Masiakos. *Analysis and interpretation of data:* Nehra, Goldstein, Doody, Ryan, Chang, and Masiakos. *Drafting of the manuscript:* Nehra, Goldstein, and Masiakos. *Critical revision of the manuscript for important intellectual content:* Nehra, Goldstein, Doody, Ryan, Chang, and Masiakos. *Statistical analysis:* Chang. *Administrative, technical, and material support:* Ryan. *Study supervision:* Ryan and Masiakos.
Financial Disclosure: None reported.
Previous Presentation: This paper was presented at the 89th Annual Meeting of the New England Surgical Society; September 27, 2008; Boston, Massachusetts; and is published after peer review and revision.

REFERENCES

1. Bernard GR, Artigas A, Brigham KL, et al; Consensus Committee. Report of the American-European Consensus conference on acute respiratory distress syndrome: definitions, mechanisms, relevant outcomes, and clinical trial coordination. *J Crit Care.* 1994;9(1):72-81.
2. Rubenfeld GD, Caldwell E, Peabody E, et al. Incidence and outcomes of acute lung injury. *N Engl J Med.* 2005;353(16):1685-1693.

©2009 American Medical Association. All rights reserved.
Downloaded From: http://archsurg.jamanetwork.com/ on 04/26/2017

3. Hemmila MR, Napolitano LM. Severe respiratory failure: advanced treatment options. *Crit Care Med*. 2006;34(9)(suppl):S278-S290.
4. Amato MB, Barbas CS, Medeiros DM, et al. Effect of a protective-ventilation strategy on mortality in the acute respiratory distress syndrome. *N Engl J Med*. 1998; 338(6):347-354.
5. Ullrich R, Lorber C, Roder G, et al. Controlled airway pressure therapy, nitric oxide inhalation, prone position, and extracorporeal membrane oxygenation (ECMO) as components of an integrated approach to ARDS. *Anesthesiology*. 1999; 91(6):1577-1586.
6. Rubenfeld GD, Herridge MS. Epidemiology and outcomes of acute lung injury. *Chest*. 2007;131(2):554-562.
7. Kopp R, Dembinski R, Kuhlen R. Role of extracorporeal lung assist in the treatment of acute respiratory failure. *Minerva Anestesiol*. 2006;72(6):587-595.
8. UK Collaborative ECMO Trial Group. UK collaborative randomised trial of neonatal extracorporeal membrane oxygenation. *Lancet*. 1996;348(9020):75-82.
9. UK Collaborative ECMO Group. The collaborative UK ECMO (Extracorporeal Membrane Oxygenation) trial: follow-up to 1 year of age. *Pediatrics*. 1998;101(4): E1. doi:10.1542/peds.101.4.e1.
10. Mols G, Loop T, Geiger K, Farthmann E, Benzing A. Extracorporeal membrane oxygenation: a ten-year experience. *Am J Surg*. 2000;180(2):144-154.
11. Masiakos PT, Islam S, Doody DP, Schnitzer JJ, Ryan DP. Extracorporeal membrane oxygenation for nonneonatal acute respiratory failure. *Arch Surg*. 1999; 134(4):375-380.
12. Macha M, Griffith BP, Keenan R, et al. ECMO support for adult patients with acute respiratory failure. *ASAIO J*. 1996;42(5):M841-M844.
13. Green TP, Timmons OD, Fackler JC, Moler FW, Thompson AE, Sweeney MF; Pediatric Critical Care Study Group. The impact of extracorporeal membrane oxygenation on survival in pediatric patients with acute respiratory failure. *Crit Care Med*. 1996;24(2):323-329.
14. Peek GJ, Moore HM, Moore N, Sosnowski AW, Firmin RK. Extracorporeal membrane oxygenation for adult respiratory failure. *Chest*. 1997;112(3):759-764.
15. Zapol WM, Snider MT, Hill JD, et al. Extracorporeal membrane oxygenation in severe acute respiratory failure: a randomized prospective study. *JAMA*. 1979; 242(20):2193-2196.
16. Morris AH, Wallace CJ, Menlove RL, et al. Randomized clinical trial of pressure-controlled inverse ratio ventilation and extracorporeal CO2 removal for adult respiratory distress syndrome. *Am J Respir Crit Care Med*. 1994;149(2, pt 1): 295-305.
17. Pranikoff T, Hirschl RB, Steimle CN, Anderson HL III, Bartlett RH. Mortality is directly related to the duration of mechanical ventilation before the initiation of extracorporeal life support for severe respiratory failure. *Crit Care Med*. 1997; 25(1):28-32.

INVITED CRITIQUE

The history of American surgery is replete with stories of initial failure, even abandonment of innovative technology, followed by eventual success through further improvisation, attention to detail, and persistence by the advocates that success was possible. The story of ECMO development is certainly a good example of the persistence principle, first in making neonatal ECMO a standard of care for the high-risk newborn with reversible pulmonary hypertension and congenital diaphragmatic hernia. Overall survival in this group now exceeds 70% based on recent Extracorporeal Life Support Organization data.

The overall experience with nonneonatal ECMO appears to be following a similar pattern of improving success based on this report by Nehra and colleagues from the Massachusetts General Hospital. The authors attribute the overall 53% survival to a better understanding of underlying respiratory disease, earlier intervention in selected patients, careful monitoring, and knowledge of the natural history of specific disease. This is coupled with improved ECMO technology, better ECMO equipment, and the dedication of an ECMO team for fine adjustments throughout the ECMO run. Patient selection must be emphasized to prevent coagulopathy and to exclude patients with intracranial hemorrhage or advanced age. Most cannulations are venovenous to avoid carotid ligation or reconstruction with the increased risk of stroke or infarct in older patients.

The poorest outcomes reported in patients with trauma and immunocompromise following organ transplant and chemotherapy are a reminder of the limitations of this application to patient care. Certain conditions such as ARF following a stem cell transplant may be beyond the scope of this modality. Also not mentioned are the enormous cost and dedication required to making nonneonatal ECMO successful, a reminder that only a few centers having a strong prior experience with neonatal ECMO should embark on the program. A multicenter trial with strict adherence to guidelines will help to clarify future directions.

Robert J. Touloukian, MD

Correspondence: Dr Touloukian, Department of Pediatric Surgery, Yale University School of Medicine, 333 Cedar St, New Haven, CT 06510 (robert.touloukian@yale.edu).
Financial Disclosure: None reported.

©2009 American Medical Association. All rights reserved.
Downloaded From: http://archsurg.jamanetwork.com/ on 04/26/2017