Mechanical circulatory support for the failing heart has been extensively used as a bridge to heart transplantation in both adult and pediatric populations. Extracorporeal membrane oxygenation (ECMO) has long been the primary means of mechanical support for pediatric patients with end-stage cardiac failure. However, ECMO is associated with many known complications, including thromboembolic events, bleeding, immobilization, infection, end-organ dysfunction, and risk of neurological impairment, thus making the need for alternative methods of pediatric mechanical circulatory support necessary. Bridge to transplant with ECMO support is associated with high waitlist mortality and a poor survival to hospital discharge. Current organ allocation algorithms have been developed to direct hearts to the sickest recipients to mitigate death while waiting. Such a strategy may result in suboptimal post-transplant survival for certain high-risk candidates, including those on ECMO. In the evolving era of mechanical support, outcomes must be closely examined to determine the appropriateness of existing allocation algorithms, criteria for candidacy for heart transplantation, and the effect of different technologies as a bridge to transplant.

Clinical Perspective on p 969
The purpose of this study was to describe and analyze the outcomes for pediatric patients waitlisted on or transplanted from ECMO support in comparison with those without ECMO support and to attempt to define risk factors associated with worse outcomes so as to gain an understanding of when it might be futile to perform a transplant on candidates on ECMO.

Methods
Patient Population and Data Collection
This study uses data from the Pediatric Heart Transplant Study (PHTS) database, an event-driven, multicenter, prospective registry.
of children <18 years of age listed for primary transplantation from 35 pediatric heart transplantation centers in North America and the United Kingdom (Data Supplement). PHTS data collection and management have been described previously.\textsuperscript{13} Institutional Review Board approval was obtained at the transplant centers and the data analysis and coordinating center.

All patients who were listed for heart transplantation between January 1, 1993 and December 31, 2013 with a record of ECMO as a bridge to transplant were included. Comparisons were made to all patients in the registry who were not bridged to transplantation from ECMO support. Data collected included demographics, United Network for Organ Sharing status at listing, support at listing (intravenous inotropes, ventilator, prostanoglandin, ECMO, and ventricular assist device [VAD]), timing of ECMO support or VAD placement post listing, hemodynamics at listing and any during follow-up, human leukocyte antigen sensitization, surgical palliation while waiting, clinical condition at listing, death while waiting, delisting, indications for removal from waitlist, transplant United Network for Organ Sharing status at transplant, support at the time of transplant (eg, ECMO and VAD), cardiopulmonary bypass time, ischemic time, donor characteristics, hospital stay, days in intensive care unit, date of most recent follow-up, incidence of primary graft failure, rejection, infection, malignancies, allograft vasculopathy, death post-transplant, and cause of death.

### Statistical Methods

Standard Kaplan–Meier and parametric analyses were used for survival analysis. Competing-outcome methods were used to analyze outcome after listing.\textsuperscript{14} Multivariate analysis in the hazard-function domain was used to identify risk factors for death while waiting, death after transplant, and overall survival after listing, including death while waiting and death after transplant using a step-wise selection technique.\textsuperscript{15} Candidate variables entered into the multivariable risk factor analysis for death after listing (censored at transplant) included demographics at listing, blood type, listing status, underlying cardiac diagnosis, surgical history, other clinical diagnoses/comorbidities, and hemodynamics. Variables entered into the multivariable risk factor analysis for death after transplant included demographics at transplant, status at transplant, underlying cardiac diagnosis, surgical history at listing, other clinical diagnoses/comorbidities, hemodynamics at transplant, donor variables (demographics, blood type, and medical history), and donor–recipient mismatch variables (race, sex, age, blood group, and body surface area ratio).

The authors had full access to the data and take responsibility for its integrity. All authors have read and agree to the article as written.

### Results

#### Patient Population

Patient demographics and clinical characteristics at listing and transplant are summarized in Table 1. Of the 5360 patients listed over this time period, there were 453 (8%) patients listed on ECMO support at a median age of 0.56 (0.05–2.69) years, who were significantly younger, smaller, sicker, and more likely to have renal insufficiency than those not supported on ECMO at listing. Fifty-eight percent had a diagnosis of congenital heart disease. Of the 3826 transplanted patients, 203 (5%) were on ECMO support at a median age of 0.80 (0.22–4.37) years, who were similarly younger, smaller, sicker, and more likely to have renal insufficiency than those not on ECMO at transplant. Patients on ECMO support at the time of transplant had a significantly shorter waitlist duration (24 versus 93 days; \(P<0.0001\)). One hundred thirteen patients (56%) had a diagnosis of congenital heart disease. Table 2 gives the frequencies at listing by age at listing of patients on ECMO.

#### Table 1. Patient Demographics and Clinical Characteristics at Listing and at Transplant

<table>
<thead>
<tr>
<th>Demographics</th>
<th>ECMO (n=453)</th>
<th>No ECMO (n=4907)</th>
<th>P Value</th>
<th>ECMO (n=203)</th>
<th>No ECMO (n=3623)</th>
<th>P Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Male</td>
<td>241 (53%)</td>
<td>2729 (56%)</td>
<td>0.3182</td>
<td>111 (55%)</td>
<td>1984 (55%)</td>
<td>0.9819</td>
</tr>
<tr>
<td>White</td>
<td>323 (71%)</td>
<td>3469 (71%)</td>
<td>0.7857</td>
<td>143 (70%)</td>
<td>2540 (70%)</td>
<td>0.9190</td>
</tr>
<tr>
<td>Age, y (mean±SD)</td>
<td>2.5 (±4.0)</td>
<td>5.6 (±6.1)</td>
<td>&lt;0.0001</td>
<td>3.2 (±4.6)</td>
<td>6.4 (±6.2)</td>
<td>&lt;0.0001</td>
</tr>
<tr>
<td>BSA, m² (mean±SD)</td>
<td>0.50 (±0.40)</td>
<td>0.77 (±0.56)</td>
<td>&lt;0.0001</td>
<td>0.55 (±0.42)</td>
<td>0.83 (±0.55)</td>
<td>&lt;0.0001</td>
</tr>
<tr>
<td>Cause: congenital</td>
<td>262 (58%)</td>
<td>2549 (52%)</td>
<td>0.0163</td>
<td>113 (56%)</td>
<td>1741 (48%)</td>
<td>0.0347</td>
</tr>
<tr>
<td>Waitlist time, d</td>
<td>…</td>
<td>2549 (52%)</td>
<td>0.0163</td>
<td>93 (±202)</td>
<td>24 (±45)</td>
<td>&lt;0.0001</td>
</tr>
<tr>
<td>Status at listing</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Status 1</td>
<td>449 (99.8%)</td>
<td>3797 (78%)</td>
<td>&lt;0.0001</td>
<td>197 (98%)</td>
<td>2808 (78%)</td>
<td>&lt;0.0001</td>
</tr>
<tr>
<td>Ventilator</td>
<td>419 (92%)</td>
<td>1105 (23%)</td>
<td>&lt;0.0001</td>
<td>159 (78%)</td>
<td>728 (20%)</td>
<td>&lt;0.0001</td>
</tr>
<tr>
<td>Inotropes</td>
<td>375 (83%)</td>
<td>2773 (57%)</td>
<td>&lt;0.0001</td>
<td>170 (84%)</td>
<td>2076 (57%)</td>
<td>&lt;0.0001</td>
</tr>
<tr>
<td>Clinical condition at listing</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Failure to thrive</td>
<td>44 (10%)</td>
<td>940 (19%)</td>
<td>&lt;0.0001</td>
<td>23 (11%)</td>
<td>677 (19%)</td>
<td>0.0083</td>
</tr>
<tr>
<td>Renal insufficiency</td>
<td>40 (9%)</td>
<td>156 (3%)</td>
<td>&lt;0.0001</td>
<td>19 (9%)</td>
<td>111 (3%)</td>
<td>&lt;0.0001</td>
</tr>
<tr>
<td>Arrhythmias</td>
<td>139 (31%)</td>
<td>1148 (23%)</td>
<td>0.0005</td>
<td>57 (28%)</td>
<td>887 (24%)</td>
<td>0.2474</td>
</tr>
</tbody>
</table>

BSA indicates body surface area; and ECMO, extracorporeal membrane oxygenation.

#### Table 2. Age of Listed Patients by the Presence and Type of Pretransplant Mechanical Support

<table>
<thead>
<tr>
<th>Age at Listing</th>
<th>ECMO</th>
<th>VAD</th>
<th>Neither ECMO nor VAD</th>
</tr>
</thead>
<tbody>
<tr>
<td>n</td>
<td>n</td>
<td>%</td>
<td>n</td>
</tr>
<tr>
<td>&lt;1 mo</td>
<td>913</td>
<td>128</td>
<td>14.0</td>
</tr>
<tr>
<td>1 mo to &lt;1 y</td>
<td>1293</td>
<td>141</td>
<td>10.9</td>
</tr>
<tr>
<td>1 to &lt;5 y</td>
<td>1066</td>
<td>100</td>
<td>9.4</td>
</tr>
<tr>
<td>5 to 10 y</td>
<td>615</td>
<td>45</td>
<td>7.3</td>
</tr>
<tr>
<td>&gt;10 y</td>
<td>1473</td>
<td>39</td>
<td>2.7</td>
</tr>
<tr>
<td>Total</td>
<td>5360</td>
<td>453</td>
<td>8.5</td>
</tr>
</tbody>
</table>

ECMO indicates extracorporeal membrane oxygenation; and VAD, ventricular assist device.
Figure 1. Pediatric Heart Transplant Study (PHTS), 1993 to 2013, survival (A) overall (post-listing and post-transplant), (B) after listing for patients waitlisted on ECMO support (censored at transplant), and (C) after transplant for patients transplanted from extracorporeal membrane oxygenation (ECMO) support. MCSD indicates mechanical circulatory support device.

A

Overall Survival by MCSD Type at Listing
PHTS Listed Patients 1993-2013

B

Post-Listing Survival by MCSD Type at Listing
PHTS Listed Patients 1993-2013

C

Post-Transplant Survival by MCSD Type at Transplant
PHTS Transplanted Patients 1993-2013

Shaded areas indicate 70% confidence limits
p (log-rank) = <.0001
Event: Death after listing, not censored at transplant

Shaded areas indicate 70% confidence limits
p (log-rank) = <.0001
Event: Death after listing, censored at transplant

Shaded areas indicate 70% confidence limits
p (log-rank) = <.0001
Event: Death after Transplant
Dipchand et al  ECMO as a Bridge to Pediatric Heart Transplant 963

support (n=453), VAD (n=198), and neither ECMO nor VAD (n=4709). Age at the time of listing on ECMO support was <1 month (n=128; 28%), 1 month to 1 year (n=141; 31%), 1 to 5 years (n=100; 22%), 5 to 10 years (n=45; 10%), and >10 years (n=39; 9%). Of the total number of listed patients, 668 transitioned to VAD support while listed (12%) but were analyzed according to their support at the time of listing or at the time of transplant as appropriate (73 of these patients were on ECMO support and transitioned to VAD).

Overall Survival

Overall survival post listing and post transplant for patients waitlisted on ECMO is depicted in Figure 1A (including deaths and follow-up after transplant) with a significantly decreased overall survival for this group (P<0.0001).

ECMO at Listing, Death While Waiting

Patients waitlisted on ECMO support had significantly decreased survival post-listing (censored at transplant) compared with patients on VAD support or no mechanical support (P<0.0001; Figure 1B). Figure 2 shows the competing outcomes after listing for ECMO, VAD, and neither ECMO nor VAD. Overall waitlist mortality by 1 and 6 months post listing for any pediatric patient waitlisted on ECMO was 28% and 35%, respectively, in contrast to the remarkably low waitlist mortality for VAD patients of 6% and 12%, respectively. By 12 months post listing, 49% of patients listed on ECMO support were transplanted compared with 79% of VAD patients and 72% of all others (Figure 2). Causes of death post listing for patients on ECMO are summarized in Table 3.

Effect of Age on Post-Listing Survival

Younger age at listing was significantly associated with waitlist mortality, with the smallest of infants (<1 month) having the highest mortality, even without a need for mechanical support (Figure 3A). This was worsened significantly by the need for ECMO support at the time of listing and was seen in all age groups (Figure 3B). The youngest infants continued to have the worst outcomes with a waitlist mortality of 67% by 3 months post listing if they were on ECMO support at the time of listing (P<0.0001).

Effect of Other Risk Factors on Post-Listing Survival

The PHTS database did not begin to accurately capture duration of mechanical support until January 1, 2005.

Table 3. Cause of Death Post Listing and Post Transplant for Patients on Extracorporeal Membrane Oxygenation

<table>
<thead>
<tr>
<th>Primary Cause of Death</th>
<th>Post-Listing (n=157)</th>
<th>Post-Transplant (n=77)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Accidental</td>
<td>15</td>
<td>3</td>
</tr>
<tr>
<td>Anoxic insult</td>
<td>3</td>
<td>3</td>
</tr>
<tr>
<td>Coronary artery disease</td>
<td>20</td>
<td>4</td>
</tr>
<tr>
<td>Fatal arrhythmia</td>
<td>7</td>
<td>1</td>
</tr>
<tr>
<td>Infection</td>
<td>9</td>
<td>4</td>
</tr>
<tr>
<td>Postoperative haemorrhage</td>
<td>3</td>
<td>5</td>
</tr>
<tr>
<td>Pulmonary hypertension/RV failure</td>
<td>...</td>
<td>1</td>
</tr>
<tr>
<td>Rejection, hyperacute</td>
<td>...</td>
<td>1</td>
</tr>
<tr>
<td>Rejection, acute</td>
<td>...</td>
<td>4</td>
</tr>
<tr>
<td>Respiratory failure</td>
<td>6</td>
<td>4</td>
</tr>
<tr>
<td>Sudden cardiac death</td>
<td>6</td>
<td>6</td>
</tr>
<tr>
<td>Unknown</td>
<td>...</td>
<td>3</td>
</tr>
<tr>
<td>Other</td>
<td>88</td>
<td>38</td>
</tr>
</tbody>
</table>

RV indicates right ventricle.
Figure 4 illustrates survival after listing by duration of time on ECMO before listing, which did not seem to have a significant effect on survival post-listing overall ($P=0.66$). In univariate analysis, renal insufficiency did not have a significant effect on overall survival ($P=0.12$), although it is notable that a significant proportion of patients on ECMO had renal insufficiency (Table I).

**Effect of Underlying Cardiac Diagnosis on Outcomes Post-Listing**

There was a significant difference in survival based on underlying cause (Figure 5A), with patients with myocarditis having the best overall survival post-listing, followed by cardiomyopathy and subsequently a diagnosis of congenital heart disease ($P=0.0008$). This being said, of the 59 patients with myocarditis, only 10 were removed from the list for recovery. Only 7 of the 25 transplanted patients with myocarditis on ECMO at listing were not on ECMO at the time of transplant.

**ECMO at Transplant, Death Post-Transplant**

Patients transplanted while on ECMO support had significantly decreased survival post-transplant compared with patients on VAD support or no mechanical support ($P<0.0001$; Figure 1C). Patients with myocarditis had the worst outcomes when transplanted from ECMO support, followed by congenital heart disease, with patients with cardiomyopathy having the best post-transplant survival ($P=0.0005$; Figure 5B). Infants <1 year of age had significantly worse post-transplant survival when transplanted from ECMO ($P<0.0001$; Figure 6).

**ECMO at Listing and at Transplant and Effect on Overall Survival**

Table 4 summarizes the scenarios for mechanical support as a bridge to transplantation in the transplant recipients. Figure 7 illustrates the survival for each of the 4 possible ECMO combinations (there were 46 patients listed on ECMO but were weaned and removed from listing because they were considered too well. These patients were censored at the time of removal from listing.) Notably, if a patient was on ECMO at listing but weaned off before transplantation or converted to VAD, their outcome was just as good as not being on ECMO at the time of listing or transplantation. ECMO at the time of transplantation (with or without ECMO support at the time of listing) was significantly associated with worse outcomes ($P<0.0001$).

Unadjusted hazard ratio for death while waiting for patients waitlisted on ECMO censored at transplant was 2.46 ($P<0.0001$). After adjustment, the hazard ratio remained
significant at 1.73 ($P=0.03$). Table 5 summarizes the risk factors for death on the waitlist, censored at transplant, from the multivariable hazard analysis.

On multivariate analysis, overall survival after transplantation for patients on ECMO at the time of transplantation was not affected by age, ischemic time, or duration of time on ECMO. However, lower weight (risk ratio, 1.37 for a 10-kg decrease in weight; $P=0.04$), higher serum creatinine (risk ratio, 2.36 for a 1-unit increase in creatinine; $P=0.007$), and an underlying diagnosis of congenital heart disease or myocarditis (risk ratio, 2.68; $P=0.009$) were risk factors in the early phase (Table 6).

**Discussion**

We present a large multicentre experience with ECMO as a bridge to transplant in the pediatric population. Pediatric patients requiring ECMO support before heart transplant have poor outcomes, and serious consideration needs to be given to the candidacy of these patients. Prioritization of donor hearts to children waitlisted on ECMO warrants careful consideration because of ECMO’s high pre- and post-transplant mortality, most specifically infants <1 year of age, a diagnosis of congenital heart disease, and patients with renal insufficiency.

Single-center reports of waitlist mortality from ECMO range from 29% to 61% in small cohorts of patients. Almond et al recently reported on a merged cohort from both the Organ Procurement and Transplant Network and the Extracorporeal Life Support Organization who were bridged to transplantation from ECMO support with overall waitlist mortality in this cohort of 28%, similar to the 35% at 6 months found in this analysis. However, infants fared much worse in the current analysis with a waitlist mortality of >50% at 3 months. We did not see an association between duration of

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**Figure 4.** Effect on overall post-listing survival by (A) time on extracorporeal membrane oxygenation (ECMO) before listing, 2005 to 2013, and (B) history of renal insufficiency, 1993 to 2013. PHTS indicates Pediatric Heart Transplant Study.
time on ECMO before listing and waitlist mortality, perhaps being related to this being the most recent cohort of patients after 2005 and the lack of data available before this time. Diagnosis of congenital heart disease in and of itself, as has been reported elsewhere, was associated with the highest wait-list mortality.\(^5,11,18\) Unfortunately, listed patients on ECMO support were more likely to be younger and have a diagnosis of congenital heart disease (Table 1), pointing already to the problem of accumulation of multiple risk factors in these complex patients.

As has been recognized by others, survival post transplant from ECMO support is also clearly suboptimal compared with other transplant recipients. Survival to hospital discharge post-transplant in single-center reports ranges from 66% to 100%,\(^4,8,9,16,17,19\) with 1-year survival ranging from 67% to 83% and 5 year survival from 44% to 54%.\(^7,8,13,19\)

Despite these overall poorer outcomes reported using ECMO, there are subpopulations of patients on ECMO who clearly are at higher risk of pre- and post-transplant mortality. Identification of risk factors associated with a poor outcome on ECMO would be helpful for clinical decision making and for counseling of parents. The key areas of import would be (1) identification of the patient who should not be placed on to ECMO support as a bridge to transplantation because of a prohibitively high post-listing and post-transplantation morbidity and (2) identification of the patient already on ECMO who acquires a risk factor that
would make further support and transplantation futile. These 2 points are paramount in the era of significant organ donor shortages, especially in the infant population. Previous reports are predominantly single center and small numbers that make risk factor analysis not feasible.4,5,8–10,17,19 We also need to learn through additional analysis about the effect of converting these high-risk patients to VAD support.

Interestingly, age, ischemic time, and time on ECMO support before listing did not affect post-transplant survival in the ECMO cohort; the latter being somewhat surprising given the reported effect on survival of length of time on ECMO post heart transplant5,8,17 and post cardiotomy (albeit in a single-center experience).7 In fact, Almond et al18 reported that an ECMO run of >14 days predicted nonsurvival in the larger Organ Procurement and Transplant Network cohort. Perhaps this discrepancy can be explained by an era effect with the data extending back for a 15-year time period in the report by Almond et al18 compared with a more contemporary cohort (2005–2013) from PHTS. In addition, the total time on ECMO was not taken into account in this analysis.

Although a diagnosis of myocarditis boded well for post-listing survival, it was associated with the lowest post-transplant survival from ECMO, which has also been observed in other series, and hypothesized to be related to immune activation in the setting of active myocarditis or recurrent viral infection in the transplanted heart under immunosuppression.20 The effect of a diagnosis of congenital heart disease on post-ECMO and post-transplant survival varies in single-center experiences from not significantly different8 to survival rates as low as 25%,5 perhaps related to center experience and volume among other factors. However, in this larger registry-based analysis, those with a diagnosis of congenital heart disease clearly fare poorly. The effect of impaired renal function has also produced conflicting results with some reports of a negative effect8,18,19 and 1 report showing no significant effect.4 In this study, 1-unit incremental increases in serum creatinine was significantly associated with worse outcome in this larger series and bears strong consideration as a risk factor.

Although not the focus of this analysis, we have noted the important effect that VAD support has had on post-listing and post-transplant survival. This has also been observed in a previous PHTS study and in the registry for the International Society for Heart and Lung Transplantation.1,21 Both studies, as well as the present one, have demonstrated that outcomes on VAD are now equivalent to outcomes without VAD support. Further analysis is required to determine whether these excellent results can be recapitulated for pediatric ECMO patients who are converted to VADs in the pretransplant period. In most cases, a VAD can be implanted without previous ECMO support. However, there are certain circumstances

Table 4. Summary of Possible Combinations of Mechanical Support at Listing and at Transplantation in the Transplant Recipients

<table>
<thead>
<tr>
<th>At Listing</th>
<th>At Transplant</th>
<th>Died Waiting</th>
<th>Alive Waiting</th>
<th>Total</th>
</tr>
</thead>
<tbody>
<tr>
<td>ECMO</td>
<td>135 42 42</td>
<td>56 13 88</td>
<td>2 7 68</td>
<td>453</td>
</tr>
<tr>
<td>VAD</td>
<td>1 136 14</td>
<td>5 14 6</td>
<td>1 18 3</td>
<td>198</td>
</tr>
<tr>
<td>Neither</td>
<td>67 295 3094</td>
<td>44 52 531</td>
<td>3 32 591</td>
<td>4709</td>
</tr>
<tr>
<td>Subtotal</td>
<td>203 473 3150</td>
<td>105 79 625</td>
<td>6 57 662</td>
<td>5360</td>
</tr>
<tr>
<td>Total</td>
<td>3826 809</td>
<td>725</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

ECMO indicates extracorporeal membrane oxygenation; and VAD, ventricular assist device.
where initial ECMO stabilization is desired. Adult transplant programs have increasingly been using ECMO stabilization for INTERMACS 1 patients.22 There may also be certain subsets of patients such as young children with single ventricle, for whom short-term support with ECMO may be more practical than available pulsatile VAD support.

Deceased organ donor availability remains the limiting factor in heart transplantation, more so in pediatrics—especially young infants. Current organ allocation algorithms have been developed to direct hearts to the sickest recipients to mitigate death while waiting. Such a strategy may reduce post-transplant survival as evidenced in this analysis by the 69.3% 1-year survival after transplantation from ECMO support in comparison with 89.7% for those not requiring ECMO support. The concept of net survival benefit from transplantation in adults has been explored by Singh et al23 in an adult cohort in the United States. The accompanying clinical perspective on children concluded that sicker children on the waiting list benefit more from heart transplantation unless the post-transplant mortality is predicted to be too high. Where does one draw the line? For an individual patient on ECMO, mortality is close to 100% without transplantation, and it is up to the treating medical team to decide whether bridging to transplant is a feasible option. However, knowledge of the risk factors and likelihood of a good outcome should be considered in this decision making. In this evolving era of mechanical support, outcomes must continue to be closely examined to determine the appropriateness of existing allocation algorithms, criteria for candidacy for heart transplantation, and the effect of different technologies as a bridge to transplantation.

Although this reflects a large, multicenter cohort of >400 patients supported with ECMO as a bridge to heart transplantation, when seeking factors that influence survival, the numbers in subgroups are small making robust statistical statements challenging. Individual institutions contributing data to the PHTS may well have different criteria for listing and bridging patients to heart transplantation. The data forms are not all inclusive, which limited the ability to identify potential risk factors. Despite these limitations, the information is valuable in predicting outcomes and counseling families.

**Conclusions**

Pediatric patients requiring ECMO support before heart transplant generally have poor outcomes. Identifiable subgroups fare worse, whereas those weaned off before transplantation fare better. Serious consideration needs to be given to the candidacy of these patients, especially in light of the evolving and improving results using VAD support as a bridge to transplant. Prioritization of donor hearts to children waitlisted on ECMO warrants careful consideration because of ECMO’s high pre-and post-transplant mortality.

**Table 5. Multivariable Hazard of Death After Listing Censored at Transplant**

<table>
<thead>
<tr>
<th>Risk Factors</th>
<th>Early Phase of Risk</th>
<th>Relative Risk</th>
<th>P Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Age at listing (younger)*</td>
<td></td>
<td>1.41</td>
<td>&lt;0.0001</td>
</tr>
<tr>
<td>ECMO at listing</td>
<td></td>
<td>1.73</td>
<td>0.03</td>
</tr>
<tr>
<td>No myocarditis</td>
<td></td>
<td>1.93</td>
<td>0.01</td>
</tr>
<tr>
<td>Nondilated cardiomyopathy</td>
<td></td>
<td>4.23</td>
<td>0.0003</td>
</tr>
</tbody>
</table>

ECMO indicates extracorporeal membrane oxygenation.
*In the model on the natural log scale, compares 1-year old with 10-year old.

**Table 6. Pretransplant Risk Factor Multivariate Analysis for Death Post-Transplant in Patients on Extracorporeal Membrane Oxygenation at the Time of Transplant (n=203)**

<table>
<thead>
<tr>
<th>Pre-Transplant Risk Factors</th>
<th>Early Phase of Risk</th>
<th>Relative Risk</th>
<th>P Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cause: congenital or myocarditis</td>
<td></td>
<td>2.68</td>
<td>0.009</td>
</tr>
<tr>
<td>Creatinine at transplant (higher)</td>
<td></td>
<td>2.36*</td>
<td>0.007</td>
</tr>
<tr>
<td>Weight at transplant (lower)</td>
<td></td>
<td>1.37†</td>
<td>0.04</td>
</tr>
</tbody>
</table>

*Represents the increased risk of a 1-unit increase in creatinine.
†Represents the increased risk of a 10-kg decrease in weight.
ECMO as a Bridge to Pediatric Heart Transplant

Dipchand et al

Disclosures

None.

References


CLINICAL PERSPECTIVE

Children requiring extracorporeal membrane oxygenation (ECMO) have historically been the sickest of the sick, toward whom donor hearts are preferentially directed within the current organ allocation algorithms to mitigate death while waiting. Historically, this strategy translated into suboptimal post-transplant survival. The institution of ventricular assist device (VAD) support has changed the landscape considerably. Accordingly, clinicians and policy makers need to determine what role ECMO should play in the support of children needing heart transplantation. As technology and experience evolves, outcomes must be examined to determine the appropriateness of the existing organ allocation schema, criteria for candidacy for heart transplantation, and the effect of novel VAD support strategies as a bridge to transplant. We performed an analysis of a large cohort of pediatric patients listed for a heart transplant to observe the effect of the use of mechanical circulatory support, most specifically ECMO, on waitlist and post-transplantation outcomes. Our results showed a striking difference between ECMO support and VAD support on patient outcomes, further emphasizing the poor outcomes for children requiring ECMO support before heart transplantation. This suggests that strategies aimed at optimizing the use of existing VADs and developing more pediatric-specific VADs may have a further significant effect on the survival of children with end-stage heart disease requiring transplantation. Future work must focus on novel VAD technology such that it may be extended to the smallest infants and children and those with complex forms of congenital heart disease.
Extracorporeal Membrane Oxygenation as a Bridge to Pediatric Heart Transplantation: Effect on Post-Listing and Post-Transplantation Outcomes
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Supplement

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