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# Prospective trial of a pediatric ventricular assist device

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ORIGINAL ARTICLE

# Prospective Trial of a Pediatric Ventricular Assist Device

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## ABSTRACT

### BACKGROUND

Options for mechanical circulatory support as a bridge to heart transplantation in children with severe heart failure are limited.

### METHODS

We conducted a prospective, single-group trial of a ventricular assist device designed specifically for children as a bridge to heart transplantation. Patients 16 years of age or younger were divided into two cohorts according to body-surface area (cohort 1, <0.7 m²; cohort 2, 0.7 to <1.5 m²), with 24 patients in each group. Survival in the two cohorts receiving mechanical support (with data censored at the time of transplantation or weaning from the device owing to recovery) was compared with survival in two propensity-score–matched historical control groups (one for each cohort) undergoing extracorporeal membrane oxygenation (ECMO).

### RESULTS

For participants in cohort 1, the median survival time had not been reached at 174 days, whereas in the matched ECMO group, the median survival was 13 days (P<0.001 by the log-rank test). For participants in cohort 2 and the matched ECMO group, the median survival was 144 days and 10 days, respectively (P<0.001 by the log-rank test). Serious adverse events in cohort 1 and cohort 2 included major bleeding (in 42% and 50% of patients, respectively), infection (in 63% and 50%), and stroke (in 29% and 29%).

### CONCLUSIONS

Our trial showed that survival rates were significantly higher with the ventricular assist device than with ECMO. Serious adverse events, including infection, stroke, and bleeding, occurred in a majority of study participants. (Funded by Berlin Heart and the Food and Drug Administration Office of Orphan Product Development; ClinicalTrials.gov number, NCT00583661.)

SYSTOLIC HEART FAILURE CAUSES 280,000 deaths in adults annually in the United States.[1] Heart failure is much less common among children than among adults, but it is highly lethal, with 46% of children with heart failure dying or undergoing transplantation within 5 years after diagnosis, according to one estimate.[2] The survival rate among children after heart transplantation is estimated at 83% at 3 years,[3,4] but the limited availability of donor hearts for children prolongs the waiting period,[5] resulting in a high rate of death among children on waiting lists.[6-8]

Options for mechanical circulatory support as a bridge to transplantation are limited for children. The mainstay of support for small children has been extracorporeal membrane oxygenation (ECMO). The effective period of support with ECMO is typically limited to only 10 to 20 days before serious complications ensue, such as bleeding and major organ-system failure, which often preclude transplantation. The short duration of support afforded by ECMO is often inadequate, considering the current waiting times (a median of 119 days for all infants in 2008[5]). As a result, only 40 to 60% of children requiring support with ECMO survive long enough to undergo heart transplantation.[9]

The Excor Pediatric ventricular assist device (Berlin Heart) is a paracorporeal, pneumatically driven, pulsatile-flow mechanical circulatory-support device available in a wide range of sizes. We conducted a prospective study to evaluate this device as bridge therapy in children who were on waiting lists for orthotopic heart transplantation.

## METHODS

### STUDY DESIGN

In this prospective, multicenter, single-group cohort study,[10] we compared children who underwent implantation of the Excor Pediatric ventricular assist device as a bridge to transplantation with a historical control group of children who received circulatory support with ECMO. Seventeen pediatric cardiac centers in the United States and Canada participated in the trial (see the Supplementary Appendix, available with the full text of this article at NEJM.org, for a list of study sites and investigators).

The study was designed by the principal investigators and by clinical experts in pediatric trial design, hematology, and neurology in collaboration with the sponsor, Berlin Heart, and the Food and Drug Administration. Data were gathered by study coordinators at each site and were analyzed by the sponsor and independent academic statisticians in collaboration with the study investigators. The investigators had full access to the data. Data monitoring was performed by a contract research organization (Alquest). Data confidentiality was required by contractual agreement between each study site and the sponsor. The decision to submit the manuscript for publication was made by members of the publication committee (see the Supplementary Appendix) and the sponsor. All authors participated in writing, revising, and reviewing the manuscript. The academic authors and the authors who are employees of the sponsor vouch for the accuracy and completeness of the data and analysis and the fidelity of the study to the trial protocol. The study protocol (available at NEJM.org) was approved by the institutional review board at each participating center, and written informed consent was provided by a parent or legal guardian for all study participants.

### PARTICIPANT SELECTION

Children were eligible for the study if they were 16 years of age or younger, weighed between 3 and 60 kg, had two-ventricle circulation, had severe heart failure despite optimized medical treatment, and were on a waiting list for cardiac transplantation. Children who had already been receiving another form of mechanical circulatory support were allowed to participate, except for those who had received circulatory support with ECMO for 10 days or more (see Table S1 in the Supplementary Appendix for a complete list of inclusion and exclusion criteria). After enrollment, participants were stratified according to body-surface area. Cohort 1 included all participants with a body-surface area of less than 0.7 m², and cohort 2 all participants with a body-surface area of at least 0.7 m² but less than 1.5 m².

### STUDY PROTOCOL

Each participant underwent surgical implantation of an Excor Pediatric ventricular assist device, the size of which was chosen on the basis of age and body weight. Devices with stroke volumes of 10, 25, 30, 50, and 60 ml were available (Fig. S1 and S2 in the Supplementary Appendix).[11] Par-

ticipants underwent implantation of one device in the left ventricle only (left ventricular assist) or of devices in both left and right ventricles (biventricular assist) on the basis of an algorithm developed to predict right-heart performance at the time of surgery and at the clinical discretion of the surgeon performing the implantation.[10] Standardized antithrombotic therapy was recommended (Fig. S3 in the Supplementary Appendix).[10] After postoperative recovery, patients in stable condition were typically treated with aspirin, dipyridamole, and either warfarin or enoxaparin.

Study data were collected within 48 hours before device implantation; at implantation; at 1, 2, 4, and 6 weeks; at 3 and 6 months; and every 3 months thereafter while the child received cir-

culatory support with the ventricular assist device. Participants who were deemed to be acceptable candidates for a heart transplant after implantation of the device underwent transplantation if and when a suitable donor organ became available. Participants with signs of substantial ventricular recovery were weaned from the ventricular assist device, meaning that support with the device was gradually discontinued, and the pump surgically explanted.

## SELECTION OF HISTORICAL CONTROL GROUP

A historical control group of children receiving circulatory support with ECMO was selected from the Extracorporeal Life Support Organization (ELSO) registry. The ELSO registry is a multicenter, vol-

**Table 1. Characteristics of the Study Participants.***

| Variable | VAD Cohort 1 (N=24) | ECMO Matched Group for Cohort 1 (N=48)† | P Value‡ | VAD Cohort 2 (N=24) | ECMO Matched Group for Cohort 2 (N=48)† | P Value‡ |
|---|---|---|---|---|---|---|
| Age — mo§ | | | | | | |
| Median | 11.7 | 10.6 | 0.53 | 111.2 | 138.7 | 0.96 |
| Range | 2.6–45.6 | 0.1–112.3 | | 50.8–191.8 | 1.8–188.6 | |
| Weight — kg§ | | | | | | |
| Median | 9.2 | 8.8 | 0.79 | 30.7 | 36.0 | 0.96 |
| Range | 3.6–13.6 | 3.1–27.0 | | 16.0–58.1 | 4.0–59.0 | |
| Primary diagnosis — no. (%)§ | | | 0.32 | | | 0.51 |
| Congenital heart disease | 3 (12) | 8 (17) | | 6 (25) | 15 (31) | |
| Coronary artery disease | 0 | 0 | | 0 | 1 (2) | |
| Dilated cardiomyopathy or myocarditis | 19 (79) | 39 (81) | | 17 (71) | 31 (65) | |
| Hypertrophic cardiomyopathy | 1 (4) | 0 | | 0 | 0 | |
| Restrictive cardiomyopathy | 1 (4) | 0 | | 1 (4) | 0 | |
| Valvular heart disease | 0 | 1 (2) | | 0 | 1 (2) | |
| Preoperative mechanical ventilation — no. (%)§ | 20 (83) | 36 (75) | 0.42 | 11 (46) | 26 (54) | 0.50 |
| Preoperative inotrope infusion — no. (%)§ | 22 (92) | 43 (90) | 0.78 | 21 (88) | 40 (83) | 0.64 |
| Preoperative cardiac arrest — no. (%)§ | 7 (29) | 14 (29) | 1.00 | 5 (21) | 13 (27) | 0.56 |
| Body-surface area — m² | | | | | | |
| Median | 0.44 | | | 1.08 | | |
| Range | 0.23–0.62 | | | 0.71–1.66‖ | | |
| Male sex — no. (%) | 12 (50) | | | 13 (54) | | |
| INTERMACS profile status at implantation — no. (%)¶ | | | | | | |
| 1 | 11 (46) | | | 13 (54) | | |
| 2 | 13 (54) | | | 11 (46) | | |

| Table 1. (Continued.) | | | | | | |
|---|---|---|---|---|---|---|
| Variable | VAD Cohort 1 (N=24) | ECMO Matched Group for Cohort 1 (N=48)† | P Value‡ | VAD Cohort 2 (N=24) | ECMO Matched Group for Cohort 2 (N=48)† | P Value‡ |
| Preoperative ECMO — no. (%) | 6 (25) | | | 8 (33) | | |
| Preoperative centrifugal VAD — no. (%) | 2 (8) | | | 0 | | |
| Type of implant — no. (%) | | | | | | |
|    LVAD | 17 (71) | | | 14 (58) | | |
|    BiVAD | 7 (29) | | | 10 (42) | | |
| Closure of intracardiac shunt at implantation — no. (%) | 7 (29) | | | 3 (12) | | |
| Valve repair or replacement at implantation — no. (%) | 2 (8) | | | 4 (17) | | |
| Time required for cardiopulmonary bypass — min | 185±49 | | | 176±52 | | |

* Plus–minus values are means ±SD. BiVAD denotes biventricular assist device, ECMO extracorporeal membrane oxygenation, LVAD left ventricular assist device, and VAD ventricular assist device.
† The correlation coefficient for the matched propensity scores was 0.97 for cohort 1 (P<0.001) and 0.96 for cohort 2 (P<0.001).
‡ P values for comparison of the ventricular-assist cohorts with the propensity-score–matched ECMO groups were obtained with the t-test or chi-square test.
§ These variables were used in the propensity-score analysis to match historical control groups from the Extracorporeal Life Support Organization (ELSO) database with the ventricular-assist cohorts.
¶ According to the Interagency Registry for Mechanically Assisted Circulatory Support (INTERMACS),[13] a profile status of 1 indicates critical cardiogenic shock, and 2 progressive decline.
‖ One participant had a body-surface area of 1.66 m², which was outside the eligibility-criteria specifications; a protocol deviation was documented for this occurrence.

untary database that enrolls patients who receive ECMO support. A propensity-score analysis was used to match each participant who received a ventricular assist device to two children who had received support with ECMO (selected from the ELSO database). The propensity-score matching was performed separately and independently for each of the two cohorts. Details regarding the ELSO database and the propensity-score matching are provided in the Supplementary Appendix.

**STUDY OUTCOMES**

The primary efficacy end point was defined differently for the ventricular-assist and ECMO groups. For the ventricular-assist group, the primary end point was the time to death or weaning from the device with an unacceptable neurologic outcome. Death was defined as any death occurring while the child required support with the device or death within 30 days after weaning from the device or before hospital discharge, whichever was longer. An unacceptable neurologic outcome was defined as either coma or the presence of profound sensory,

motor, language, or cognitive impairment as assessed with the Pediatric Stroke Outcome Measure[12] (see the Supplementary Appendix for details of the neurologic assessments and the Pediatric Stroke Outcome Measure). Data from participants who underwent heart transplantation or who had ventricular recovery with uneventful weaning from the device were censored at the time of transplantation or weaning.

For the ECMO group, the primary end point was only the time to death (as defined above), because data on neurologic status were not available in the ELSO database. Data from patients who underwent device explantation and survived for at least 30 days were censored; the ELSO database does not specify whether such explants were due to recovery or transplantation.

In a secondary outcome assessment, outcome events were classified for a competing-risk analysis. For the ventricular-assist group, four mutually exclusive outcome events were tracked: death during receipt of circulatory support with the device; heart transplantation; failure of weaning (defined

as death or an unacceptable neurologic outcome, as defined above, within 30 days after weaning or before discharge from the hospital, whichever was longer); and successful weaning (defined as weaning from the device without death or an unacceptable neurologic outcome within 30 days after weaning or before discharge from the hospital). For the ECMO group, three mutually exclusive outcome events were tracked: death during receipt of support with ECMO, death within 30 days after weaning from the device, and removal of the device (without death within 30 days after device removal). For both groups, children who had not yet had any of these specific outcome events were classified as being alive and receiving support with the device.

Additional data were collected for the ventricular-assist group. Data on device performance (e.g., function of the driver system and the drive lines, system failures, systolic and diastolic pressures, and stroke rate) were recorded routinely while participants receiving circulatory support with the device. Functional status was assessed at each time point by determining whether the participant was sedated, intubated, eating, or ambulating. Information about functional status is provided in the Supplementary Appendix. Adverse events were documented throughout the study according to standardized definitions from the Interagency Registry for Mechanically Assisted Circulatory Support[13] (Table S3 in the Supplementary Appendix).

A clinical events committee adjudicated all adverse events, the neurologic status of patients who were considered to be weaned from the device owing to recovery, and deaths. A data and safety monitoring committee evaluated the study data every 6 months to ensure the safety of the participants and the integrity of the study (see the Supplementary Appendix).

### STATISTICAL ANALYSIS

We estimated that the median time to the primary end point for participants with the ventricular assist device would be 100 days, and the median time to the primary end point for the propensity-score–matched control group of children receiving support with ECMO would be 5 days. On the basis of these assumptions, we calculated that the inclusion of 24 participants in each ventricular-assist cohort would provide more than 99% power, with a two-sided alpha level of 0.05, to test the hypothesis that

survival with the ventricular assist device would be significantly longer than survival with ECMO.

All comparisons between the ventricular-assist and ECMO groups were performed on an intention-to-treat basis. Cumulative event rates were calculated according to the Kaplan–Meier method. For the ventricular-assist group, the time to an event was measured from the time of implantation of the ventricular assist device, regardless of whether another form of mechanical support had been in use before implantation. For the ECMO group, the time to an event was measured from the time of implantation of the ECMO device. The between-group difference in the time to the occurrence of the primary end point was assessed by means of the log-rank test within each of the two study cohorts. The duration of support with the device was compared with the use of the Wilcoxon median two-sample test.

The primary efficacy outcome was also evaluated with the use of a competing-risk analysis. The proportion of participants having each of the competing outcomes at each time point was plotted. Outcomes at 30 days and at the end of device support for the participant who received support for the longest time were compared between groups with the use of chi-square tests.

The primary safety end point was calculated as the number of serious adverse events per day during circulatory support with the ventricular assist device. A Poisson exact confidence interval was calculated, and the critical-value method was used for significance testing. Success was prospectively defined as less than 0.25 events per day for the upper bound of the 95% Poisson exact confidence interval. A two-tailed Fisher's exact test was used to compare the proportion of participants in each functional-status category at each time point with the proportion in each category before the devices were implanted.

All reported P values are two-sided. A P value of less than 0.05 was considered to indicate statistical significance, without adjustment for multiple comparisons.

## RESULTS

### STUDY PARTICIPANTS

We enrolled 48 children, 24 in each cohort, in the trial between May 2007 and December 2010. In cohort 1, the median age was 1 year and the median weight was 9 kg. In cohort 2, the median age

was 9 years and the median weight was 31 kg. In both cohorts, the cause of cardiac failure in most participants was cardiomyopathy or myocarditis, with a much smaller proportion having congenital heart disease (Table 1). The propensity-score–matching process resulted in statistically well-matched control groups (Table 1, and Table S2 in the Supplementary Appendix).

### DEVICE EFFICACY AND SUPPORT OUTCOMES

For children in cohort 1, the median duration of support with the ventricular assist device was 28 days, as compared with 5 days for the matched ECMO group (P<0.001 by the Wilcoxon median two-sample test). The longest duration of support with the device in each of these two groups was 174 days and 21 days, respectively. For children in cohort 2, the median duration of support with the device was 43 days, as compared with 5 days for the matched ECMO group (P<0.001 by the Wilcoxon median two-sample test). The longest duration of support with the device in each of these two groups was 192 days and 28 days, respectively.
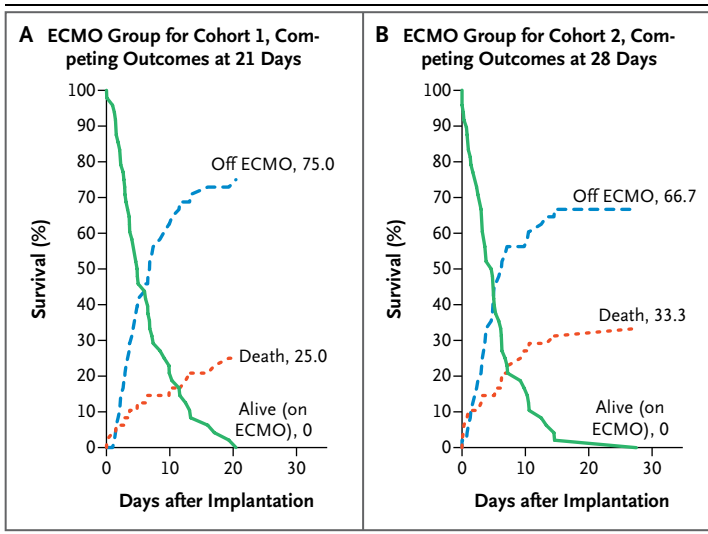
Among participants in cohort 1, the median time to the primary end point had not yet been reached at 174 days. In contrast, the median time to the primary end point in the matched ECMO group was 13 days (P<0.001 by the log-rank test) (Fig. 1A). Among participants in cohort 2, the median time to the primary end point was 144 days, as compared with 10 days in the matched ECMO group (P<0.001 by the log-rank test) (Fig. 1B).

Competing-outcome analyses are shown in Figures 2 and 3. In the ECMO group for cohort 1, at 21 days, 25% of the patients had died, and none were alive and still receiving support with ECMO (Fig. 2A). In the ECMO group for cohort 2, at 30 days, 33% of the patients had died, and none were alive and still receiving support with ECMO (Fig. 2B). In contrast, in cohort 1, at 174 days, 88% of the patients had undergone successful transplantation and 12% had died or had an unacceptable neurologic outcome after weaning from the device (Fig. 3A). In cohort 2, at 192 days, 92% of the patients had undergone successful transplantation or had been weaned from the device, and 8% had died (Fig. 3B). Overall, 88% of the participants in cohort 1 and 92% of those in cohort 2 survived to undergo either heart transplantation or weaning from the device (Table 2).
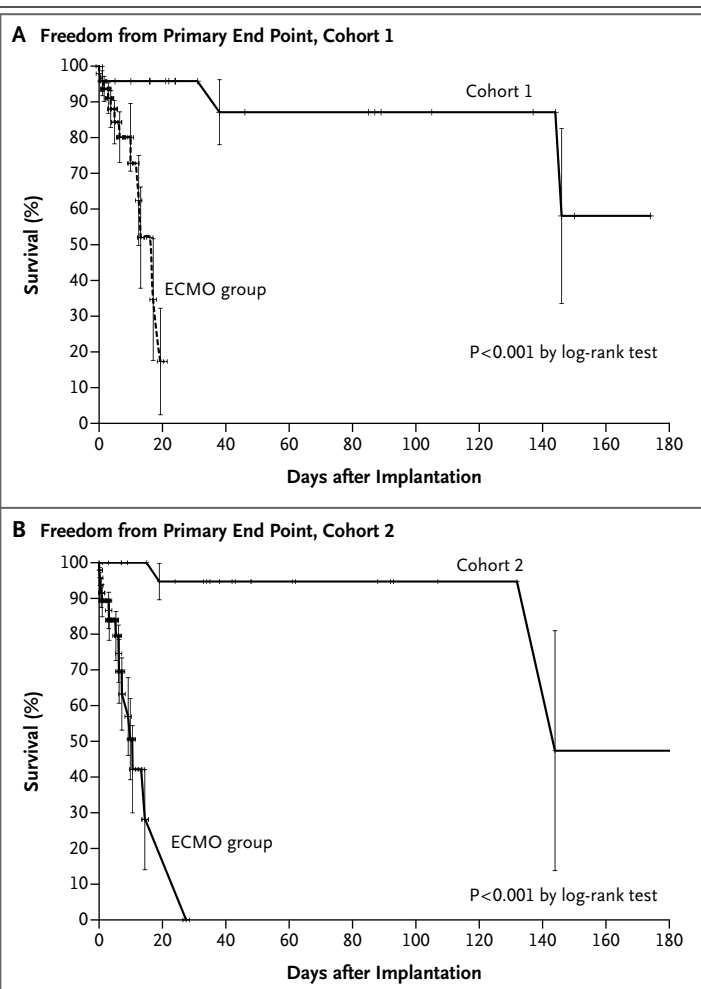


**Figure 1. Kaplan–Meier Estimates of Freedom from the Primary End Point for Patients Who Received a Ventricular Assist Device and for Matched Control Groups of Children Who Received Support with Extracorporeal Membrane Oxygenation (ECMO).**

Panels A and B show the data from cohorts 1 and 2, respectively, as compared with data from their propensity-score–matched control groups. For both ventricular-assist cohorts, the primary end point was the time to death or weaning from the device with an unacceptable neurologic outcome. Death was defined as any death occurring while the child required support with the device, or any death occurring within 30 days after weaning from the device or before discharge from the hospital, whichever was longer. An unacceptable neurologic outcome was defined as either coma or the presence of profound sensory, motor, language, or cognitive impairment as assessed with the Pediatric Stroke Outcome Measure[12] (see the Supplementary Appendix). Data from participants who underwent heart transplantation or who had ventricular recovery with uneventful weaning were censored at the time of transplantation or weaning. For the ECMO groups, the primary end point was only the time to death (as defined above), because data on neurologic status were not available in the Extracorporeal Life Support Organization (ELSO) database. Data from patients who underwent device explantation and survived for at least 30 days were censored; the ELSO database does not specify whether such explants were performed because of recovery or transplantation. Each tick mark represents an event, and I bars indicate asymmetric confidence intervals equivalent to 1 SE.

**A  ECMO Group for Cohort 1, Competing Outcomes at 21 Days**

**B  ECMO Group for Cohort 2, Competing Outcomes at 28 Days**

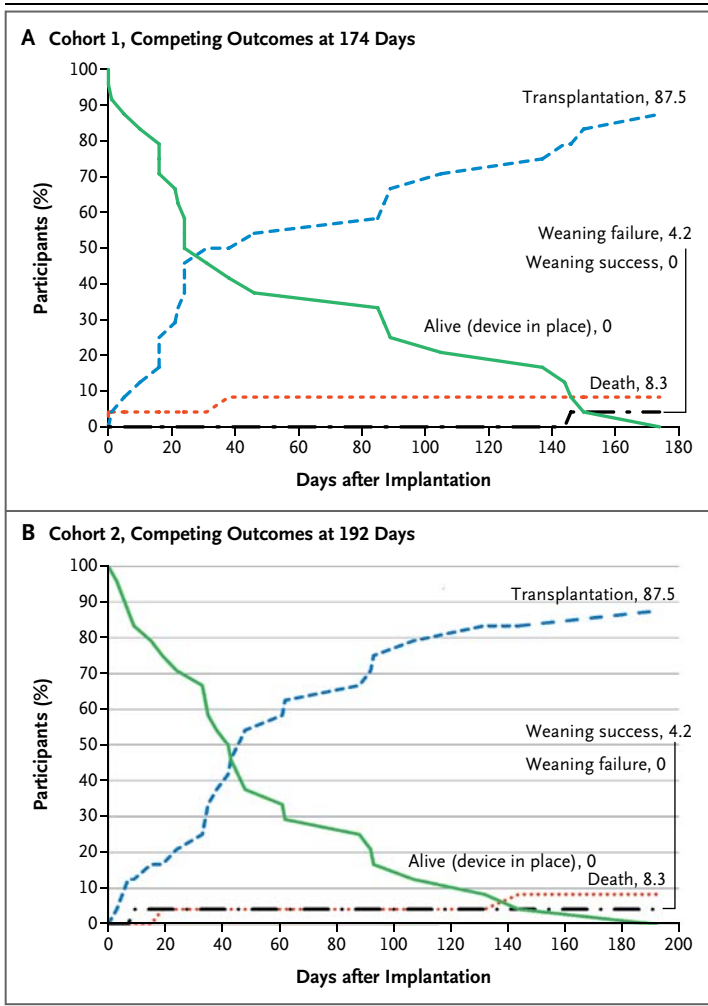**Figure 2. Competing-Outcomes Analysis of the ECMO Groups.**

Three mutually exclusive outcome events were tracked for this analysis: death occurring while the child was receiving circulatory support with ECMO, death within 30 days after weaning from the device, and device removal (without death within 30 days). Children who had not yet had any of these specific outcome events were classified as being alive and receiving circulatory support.

### ADVERSE EVENTS

The rate of serious adverse events in cohort 1 was 0.07 events per patient-day (95% confidence interval [CI], 0.06 to 0.08), and in cohort 2, the rate was 0.08 events per patient-day (95% CI, 0.06 to 0.09). The upper bounds of the 95% confidence intervals were both below the prospectively set criterion for success of 0.25.

The most common serious adverse events were major bleeding (in 42% of participants in cohort 1 and in 50% of those in cohort 2), infection (in 63% and 50%, respectively), stroke (in 29% and 29%), and hypertension (in 50% and 33%). More details regarding deaths and adverse neurologic outcomes, as well as a table of adverse events (Table S7 in the Supplementary Appendix), are provided in the Supplementary Appendix.

Forty-six pump changes occurred in cohorts 1 and 2 combined. Thrombus formation in the device was identified as the reason for 43 of these pump changes. Pump changes were required in three participants for whom no thrombus in the device was identified: one participant had multiple infarcts on computed tomography of the head, one had a neurologic event, and one had positive fungal blood cultures.



**A  Cohort 1, Competing Outcomes at 174 Days**

**B  Cohort 2, Competing Outcomes at 192 Days**

**Figure 3. Competing-Outcomes Analysis of the Ventricular-Assist Cohorts.**

Four mutually exclusive outcome events were tracked for this analysis: death occurring while the child was receiving circulatory support with the ventricular assist device, heart transplantation, weaning from the device but either dying or having an unacceptable neurologic outcome within 30 days after weaning or before discharge from the hospital (whichever was longer), and weaning from the device without death or an unacceptable neurologic outcome in the period defined above. Children who had not yet had any of these specific outcome events were classified as being alive and receiving circulatory support.

**Table 2. Efficacy Outcomes.***

| Group | No. of Children | Outcome at 30 Days | | | | | Success at 30 Days† | P Value | Outcome at End of Circulatory Support | | | | Success at End of Circulatory Support‡ | P Value |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | Receiving Circulatory Support | Received Trans-plant | Weaned with Recovery | Weaned with Poor Outcome§ | Died | | | Received Trans-plant | Weaned with Recovery | Weaned with Poor Outcome§ | Died | | |
| | | *number of children* | | | | | *no. (%)* | | *number of children* | | | | *no. (%)* | |
| VAD cohort 1 | 24 | 12 | 11 | 0 | 0 | 1 | 23 (96) | 0.048 | 21 | 0 | 1 | 2 | 21 (88) | 0.059 |
| ECMO matched group for cohort 1 | 48 | 0 | NA | 36¶ | 2 | 10 | 36 (75) | | NA | 36¶ | 2 | 10 | 36 (75) | |
| VAD cohort 2 | 24 | 17 | 5 | 1 | 0 | 1 | 23 (96) | 0.007 | 21 | 1 | 0 | 2 | 22 (92) | 0.021 |
| ECMO matched group for cohort 2 | 48 | 0 | NA | 32¶ | 6 | 10 | 32 (67) | | NA | 32¶ | 6 | 10 | 32 (67) | |

* The days by which no participants were still alive and receiving circulatory support were as follows: 174 days in cohort 1, 21 days in the ECMO group for cohort 1, 192 days in cohort 2, and 28 days in the ECMO group for cohort 2. NA denotes not available.

† Success at 30 days in the ventricular-assist group was defined as being alive and receiving circulatory support with the device, having undergone transplantation, or having been weaned from the device with an acceptable neurologic outcome within 30 days after device removal. Success at 30 days in the ECMO group was defined as being alive and receiving circulatory support with ECMO or having been successfully weaned from ECMO, either owing to transplantation or weaning without death within 30 days after device removal.

‡ Success at the end of device support in the ventricular-assist group was defined as having undergone transplantation or having been weaned from the device with an acceptable neurologic outcome within 30 days after device removal. Success at the end of device support in the ECMO group was defined as weaning from ECMO because of transplantation or recovery.

§ A poor outcome in the ventricular-assist group was defined as death or an unacceptable neurologic outcome within 30 days after weaning or before discharge from the hospital, whichever was longer. A poor outcome in the ECMO group was defined as death within 30 days after weaning from the device; data on neurologic outcomes were unavailable from the ELSO database.

¶ Data from patients who underwent device explantation and survived for at least 30 days were censored; the ELSO database does not specify whether such explants are due to recovery or transplantation.

## DISCUSSION

Adults with severe heart failure have benefited from a series of technological advances in the use of ventricular assist devices as a bridge to heart transplantation.[14-16] Progress in developing pediatric devices has been much slower because of the proportionately greater variation in size among children. Other reasons for the slow progress include biologic differences in the response to anticoagulant medicines, low levels of interest in the medical industry, and in particular, the size constraints in very small babies.

In this trial, we evaluated the use of the Excor Pediatric ventricular assist device as a bridging therapy in children who were on waiting lists for orthotopic heart transplantation. This device is available in several sizes, so that its use may be feasible in children of various ages. We compared outcomes in participants who had received a ventricular assist device to those in propensity-score–matched, historical control groups of children who received support with ECMO, the only other option for mechanical circulatory support that is currently available for small children. We found that the rate of survival to device explantation (owing to either transplantation or recovery) was markedly higher with the ventricular assist device than with ECMO. The outcome comparison was particularly stringent because a successful outcome in the ventricular-assist group included an acceptable neurologic outcome, which could not be systematically analyzed in the ECMO group.

As with the use of a ventricular assist device for circulatory support in adults, serious adverse events, including bleeding, infection, and stroke, occurred in a majority of the study participants. Although the occurrence of stroke is troubling, the stroke rate in this cohort is similar to that reported during the use of ventricular assist devices in children who had a body-surface area greater than 1.2 m² and who were treated with adult-sized ventricular assist devices.[17] The sequelae of stroke in this trial did not preclude eligibility for transplantation in the majority of participants, and the stroke-related deficits were generally mild.

An important limitation of this trial is the lack of randomization. A randomized design was contemplated, but equipoise in the medical community was lacking. The propensity-score–matching process resulted in an ECMO group that was statistically similar to the ventricular-assist group. However, it is plausible that despite propensity-score matching, the children in the ECMO group were in some respects more ill than those in the ventricular-assist group. Given that no other mechanical support device exists for these patients, we believe that children receiving support with ECMO represent the best comparison group.

In conclusion, we found that a ventricular assist device available in several sizes for use in children as a bridge to heart transplantation was associated with a significantly higher rate of survival, as compared with ECMO. Serious adverse events, including infection, stroke, and bleeding, occurred in a majority of the study participants.

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