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Temporary Circulatory Support in U.S. Children Awaiting Heart Transplantation

Vamsi V. Yarlagadda, MD,[a,c] Katsuhide Maeda, MD,[b,c] Yulin Zhang, PhD,[c] Sharon Chen, MD,[a,c] John C. Dykes, MD,[a,c] Mary Alice Gowen, RN,[c] Paul Shuttleworth, BSN,[c] Jenna M. Murray, NP,[c] Andrew Y. Shin, MD,[a,c] Olaf Reinhartz, MD,[b,c] David N. Rosenthal, MD,[a,c] Doff B. McElhinney, MD, MS,[a,c] Christopher S. Almond, MD, MPH[a,c]

ABSTRACT

BACKGROUND Extracorporeal membrane oxygenation (ECMO) has long served as the standard of care for short-term mechanical circulatory support in pediatrics. It is unknown whether newer-generation temporary circulatory support (TCS) devices afford children a meaningful survival advantage over ECMO.

OBJECTIVES This study sought to determine whether bridge-to-heart transplant survival with a TCS device is superior to ECMO after adjusting for patient differences.

METHODS All children ≤21 years of age listed for heart transplant from 2011 to 2015 who received a TCS device or ECMO as a bridge to transplant were identified using Organ Procurement and Transplantation Network data. Children supported with a TCS device were compared with a propensity score (PS)–matched cohort of children supported with ECMO as a bridge to transplant. The primary endpoint was Kaplan-Meier survival to transplant.

RESULTS The number of TCS devices implanted in children increased from ≤3 per year before 2011 to 50 in 2015. Overall, 93 patients implanted with TCS devices were included for analysis (59% left ventricular assist devices, 23% right ventricular assist devices, 18% biventricular assist devices). The most commonly used device was the CentriMag-PediMag system (65%), followed by TandemHeart (18%), Rotaflow (6%), and Impella (5%). Among 164 PS-matched patients, support duration was longer for the TCS cohort (median 19 days vs. 6 days; $p < 0.001$), and was longest for the CentriMag-PediMag (24 days vs. 6 days; $p < 0.001$) with 27% supported for >60 days. Compared with the ECMO cohort, the PS-matched TCS cohort had longer survival to transplant (hazard ratio: 0.49; 95% confidence interval: 0.30 to 0.79) and longer overall survival (hazard ratio: 0.61; 95% confidence interval: 0.39 to 0.96), with 90-day mortality before transplant that was modestly reduced (from 45% with ECMO to 39% with TCS).

CONCLUSIONS The use of TCS devices in children as a bridge to transplant has risen rapidly in recent years, led by the growth of magnetically levitated centrifugal flow pumps. Compared with conventional ECMO, TCS durations are longer, and more importantly, patient survival is superior. (J Am Coll Cardiol 2017;70:2250–60)

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From the [a]Division of Pediatrics Cardiology, Stanford University, the Lucile Packard Children's Hospital, Palo Alto, California; [b]Department of Cardiac Surgery, Stanford University, the Lucile Packard Children's Hospital, Palo Alto, California; and the [c]Heart Center and Heart Center Clinical and Translational Research Program, the Lucile Packard Children's Hospital, Palo Alto, California.
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Extracorporeal membrane oxygenation (ECMO) has long served as the standard of care for U.S. children who require short-term mechanical circulatory support (MCS) (1–6). Although ECMO is frequently life-saving, in part because of its rapid deployment capability (6), approximately one-half of all children supported with ECMO fail to survive to hospital discharge—a statistic that has not changed appreciably in >25 years (4,5).

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In recent years, a newer generation of short-term circulatory support devices, known as temporary circulatory support (TCS) devices, has become available (7–13). These devices include the Rotaflow centrifugal pump (DataScope/Maquet, Rastatt, Germany) (14), CentriMag blood pump (Thoratec, Pleasanton, California) (7–11), PediMag blood pump (Thoratec) (12,15,16), Impella heart pump (Abiomed, Danvers, Massachusetts) (15,17,18), and TandemHeart percutaneous ventricular assist device (VAD) (CardiacAssist, Pittsburgh, Pennsylvania) (19,20), among others. Although the growth of long-term (or durable) VADs in children is now well documented (8–20), relatively little is known about the use of TCS devices as a bridge to transplant. Specifically, it is unclear how the use of TCS devices has changed in recent years, which types of TCS devices are being used, how support durations compare to ECMO, and importantly, whether patient survival is superior to ECMO. Previous studies have been limited to case reports and single-center case series (7,9,11,12,15–17,19,20) that lack a control group or are underpowered to show differences in outcome (13,21), and may not necessarily reflect national trends owing to regional or center-specific differences in management practices and device preferences.

Thus, the specific aims of this study are: 1) to describe U.S. trends in TCS utilization as a bridge-to-transplant; 2) to determine the type and frequency of TCS devices currently being used in U.S. children; 3) to determine whether support durations are longer for TCS devices than for ECMO; and 4) to determine whether patient survival is better for TCS devices than for ECMO after adjusting for patient factors. The broader purpose of this study is to clarify which short-term devices—within a relatively crowded field of devices—are currently achieving the best outcomes to facilitate informed decisions about device selection.

METHODS

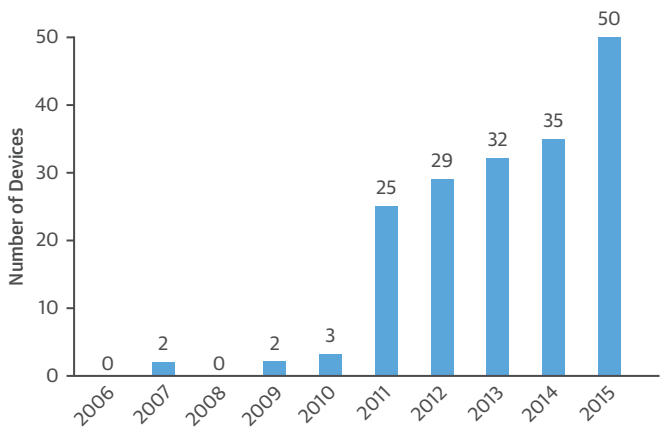
STUDY POPULATION AND DATA SOURCE. All pediatric subjects ≤21 years of age listed for heart transplant (HT) between January 2011 and December 2015 who were supported with ECMO or TCS while on the waitlist were identified using Organ Procurement and Transplantation Network (OPTN) data. Patients who received both ECMO and a TCS device were excluded. Twenty-one years of age was the cutoff age for the analysis because it is consistent with the Food and Drug Administration definition of the pediatric age group (22). OPTN is an internally audited, mandatory, government-sponsored solid-organ transplant registry that collects information on all solid organ transplants in the United States. Demographic and clinical information is reported by transplanting centers to the OPTN and is supplemented by data from the Social Security Administration. The study dates were chosen on the basis of when United Network for Organ Sharing (UNOS) began collecting data on all MCS devices used during the wait period. All patients were followed from the time of HT listing until death or the last observation on March 30, 2016.

STUDY DEFINITIONS AND OUTCOME MEASURES. The primary study hypothesis was that among children requiring short-term MCS as a bridge to transplant, children supported with a TCS device have superior survival to transplant compared with subjects supported with ECMO, after adjusting for patient factors. The secondary study hypothesis was that children supported with a TCS device have longer support durations compared with those children supported with conventional ECMO after adjusting for patient factors. TCS was defined according to the INTERMACS (Interagency Registry of Mechanically Assisted Circulatory Support) registry classification system (23) and includes all TCS devices. Survival time was defined as the time from device implant to waitlist removal due to death or clinical deterioration. Support duration was defined as the time from device implant date to device explant date (irrespective of whether the patient remained on the device until transplant), or waitlist removal if the patient remained on the same device until transplant or waitlist removal. Left ventricular assist device

ABBREVIATIONS AND ACRONYMS

BIVAD = biventricular assist device
CI = confidence interval
ECMO = extracorporeal membrane oxygenation
GFR = glomerular filtration rate
HR = hazard ratio
HT = heart transplant
LVAD = left ventricular assist device
MCS = mechanical circulatory support
OPTN = Organ Procurement and Transplantation Network
PS = propensity score
RVAD = right ventricular assist device
UNOS = United Network for Organ Sharing
TCS = temporary circulatory support
VAD = ventricular assist device

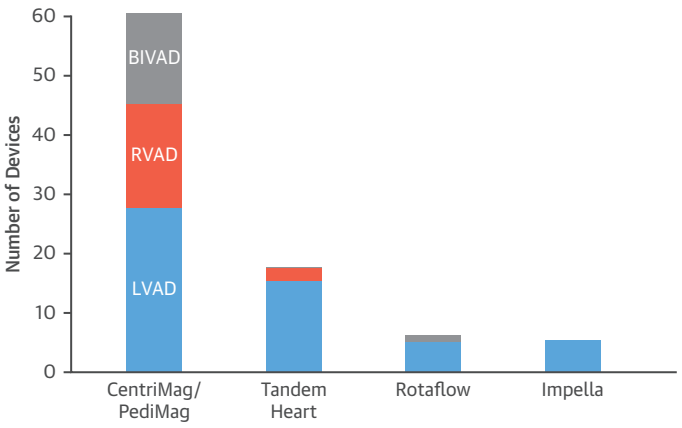
FIGURE 1 U.S. Growth of Temporary Circulatory Support Device Utilization as a Bridge to Transplant Over the Last 10 Years



The use of temporary circulatory support devices has grown substantially over the past decade based on Organ Procurement and Transplant Network Registry data.

(LVAD), right ventricular assist device (RVAD), and biventricular assist device (BIVAD) status was analyzed as reported by transplant centers. Race-ethnicity data were analyzed as reported by the transplanting center and included black (non-Hispanic black), white (non-Hispanic white), Hispanic, and other. Glomerular filtration rate (GFR) was estimated using the modified Schwartz Formula (24). Preserved renal function was defined as a GFR >60 ml/min/1.73 m^2, moderate renal dysfunction as a GFR between 30 and 60 ml/min/1.73 m^2, and severe renal dysfunction as a GFR <30 ml/min/1.73 m^2 or dialysis. For children age <2 years of age, preserved renal function was defined as a GFR >30 ml/min/1.73 m^2, moderate renal dysfunction as a GFR between 15 and 30 ml/min/1.73 m^2, and severe renal dysfunction as a GFR <15 ml/min/1.73 m^2 or dialysis. Patient insurance status, categorized as Medicaid or non-Medicaid, was analyzed as reported by transplant centers.

FIGURE 2 Type and Frequency of Temporary Circulatory Support Device Brands Used in Children as a Bridge to Transplant



The most common temporary circulatory support device brand used in children was the Thoratec CentriMag/PediMag system (Thoratec, Pleasanton, California), which accounted for the majority of device implants, followed by the TandemHeart system (CardiacAssist, Pittsburgh, Pennsylvania), the Maquet Rotaflow System (DataScope/Maquet, Rastatt, Germany), and the Impella system (Abiomed, Danvers, Massachusetts). BIVAD = biventricular assist device; LVAD = left ventricular assist device; RVAD = right ventricular assist device.

STATISTICAL ANALYSIS. Summary statistics are presented as median (25th to 75th percentile) or number (percentage). Patient characteristics were compared between study groups using Fisher exact test for categorical variables and the Wilcoxon-Mann-Whitney test for continuous ones. The Kaplan-Meier method was used to estimate overall patient survival across the waitlist and post-transplant phases. To avoid bias related to the imbalance in baseline characteristics between the TCS and ECMO groups, a propensity score (PS)-matched analysis was performed. For this analysis, a multivariable logistic regression model on the basis of patient characteristics was developed using TCS device as the dependent variable to generate a PS for each subject (probability of receiving a TCS device). Children who received a TCS device were then matched in a 1:1 ratio to those treated with conventional ECMO using the nearest neighbor matching algorithm in the MatchIt package of R (R Foundation for Statistical Computing, Vienna, Austria) with a caliper of 0.25 (25). The matched groups were compared for baseline characteristics, duration of support, and survival. Analyses were performed using R version 3.3.1.

RESULTS

STUDY COHORT. Between January 2011 and December 2015, there were a total of 3,316 children ≤21 years of age listed for isolated HT in the United States of whom 371 (11%) were identified to be supported with ECMO or TCS alone. Of these, 278 (75%) patients were supported with conventional ECMO without a TCS device and 93 (25%) patients were supported with a TCS device without ECMO.

TRENDS AND FREQUENCY OF TCS DEVICES. Figure 1 depicts the U.S. growth of TCS devices as a bridge to

transplant over the last 10 years. Overall, the number of TCS devices implanted increased from 3 or fewer per year before 2011 to 50 devices in 2015, or 27% of the 184 VADs implanted in children in 2015. During the same time, ECMO use has remained relatively stable with 80 to 100 implants per year, dipping to 77 in 2015. Figure 2 depicts the type and frequency of TCS device brands used for bridge support including LVAD, RVAD, and BIVAD support configuration. Overall, the most commonly used TCS device was the CentriMag-PediMag system (65%) followed by the TandemHeart (18%), Rotaflow (6%), Impella (5%), and all others (6%). The CentriMag-PediMag system was the most commonly used device across all support configuration (LVAD, RVAD, and BIVAD support).

Table 1 summarizes the baseline characteristics of the entire study cohort before PS matching. Compared with all 278 patients supported with ECMO, the 93 TCS patients were older (median 10.0 years of age vs. <1 year of age; $p < 0.001$), larger (median weight 30 kg vs. 7 kg; $p < 0.001$), and less likely to have congenital heart disease (30% vs. 58%; $p < 0.001$). Before PS matching, TCS patients had lower waitlist mortality, and had higher overall survival compared with ECMO patients.

Table 2 compares the baseline characteristics of the PS-matched cohort. Overall, 82 of the 93 TCS patients could be matched to a conventional ECMO patient using a caliper of 0.25, yielding a study cohort of 164 patients. This included 52 patients supported with the CentriMag-PediMag system, 14 patients supported with the TandemHeart system, 5 patients supported with the Impella system, 5 patients supported with the Rotaflow system, and 6 patients supported with various other types of TCS. After PS matching, there were no significant differences in baseline characteristics between the matched TCS patients and ECMO patients.

TABLE 1 Baseline Characteristics of Study Cohort

	All Patients (N = 371)	ECMO Cohort (n = 278)	TCS Cohort (n = 93)	p Value
Age at listing, yrs	1 (0–11)	0 (0–6)	10 (1–17)	<0.001
Age categories at listing, yrs				
1–5	242 (65)	206 (74)	36 (39)	<0.001
6–12	49 (13)	33 (12)	16 (17)	
13–17	45 (12)	24 (9)	21 (23)	
≥18	35 (9)	15 (5)	20 (22)	
Weight at listing, kg	10 (4–37)	7 (4–19)	30 (10–67)	<0.001
Weight categories at listing, kg				
<5	111 (30)	101 (36)	10 (11)	<0.001
5–10	89 (24)	73 (26)	16 (17)	
11–25	65 (18)	47 (17)	18 (20)	
26–50	32 (9)	21 (8)	11 (12)	
>50	73 (20)	36 (13)	37 (40)	
Status 1A at listing	331 (89)	247 (89)	84 (90)	0.847
Blood type O	176 (47)	126 (45)	50 (54)	0.187
Female	155 (42)	115 (41)	40 (43)	0.809
Black	84 (23)	59 (21)	25 (27)	0.256
Cardiac diagnosis at listing				
Congenital heart disease	186 (51)	158 (58)	28 (30)	<0.001
Cardiomyopathy	150 (41)	92 (34)	58 (63)	
Retransplant	29 (8)	23 (8)	6 (7)	
MCS at listing	190 (51)	158 (57)	32 (34)	<0.001
GFR at listing, ml/min/1.73 m^2	74 (48–103)	70 (46–99)	77 (53–111)	0.078
Renal function at listing				
Preserved	284 (77)	216 (79)	68 (74)	0.326
Moderate dysfunction	47 (13)	31 (11)	16 (17)	
Severe dysfunction	36 (10)	28 (10)	8 (9)	
Dialysis at listing	28 (8)	22 (8)	6 (6)	0.821
Public health insurance at listing	180 (49)	131 (47)	49 (53)	0.402

Values are median (25th to 75th percentile) or n (%).

ECMO = extracorporeal membrane oxygenation; GFR = glomerular filtration rate; MCS = mechanical circulatory support; TCS = temporary circulatory support.

SUPPORT DURATIONS FOR THE PS-MATCHED COHORTS. Figure 3 compares the support durations for the PS-matched TCS cohort relative to the ECMO cohort. Overall PS-matched TCS patients had a median support duration that was 3 times longer than the ECMO cohort (19 vs. 6 days; $p < 0.001$). Compared with the ECMO median of 6 days (25th to 75th percentile range 2 to 13 days), PS-matched CentriMag-PediMag patients had the longest support duration of 24 days (25th to 75th percentile range 12 to 62 days; $p < 0.001$). TandemHeart patients had the second longest duration (22 days; 25th to 75th percentile range 9 to 33 days; $p = 0.02$), followed by Rotaflow patients (17 days; 25th to 75th percentile range 10 to 24 days; $p = 0.03$). Although the median duration of support for Impella patients was longer than that of ECMO patients, the difference did not reach statistical significance, with only 5 matched pairs of patients ($p = 0.14$). Overall, a similar percentage of ECMO and TCS patients remained on support at the time of eventual transplant (54% vs. 68%, respectively; $p = 0.25$).

SURVIVAL FOR THE PS-MATCHED COHORTS. Figure 4 compares the waitlist, post-HT, and overall survival for the 164 PS-matched patients. Compared with the ECMO cohort, the PS-matched TCS cohort had longer waitlist survival (hazard ratio [HR]: 0.49; 95% confidence interval [CI]: 0.30 to 0.79) and longer overall survival (HR: 0.61; 95% CI: 0.39 to

TABLE 2 Baseline Characteristics of Propensity Score–Matched Study Cohort

	Matched Patients (N = 164)	ECMO Cohort (n = 82)	TCS Cohort (n = 82)	p Value
Age at listing, yrs	9 (1–16)	10 (1–16)	6 (1–16)	0.956
Age categories at listing, yrs				
1–5	71 (43)	35 (43)	36 (44)	1.000
6–12	29 (18)	15 (18)	14 (17)	
13–17	34 (21)	17 (21)	17 (21)	
≥18	30 (18)	15 (18)	15 (18)	
Weight at listing, kg	25 (10–61)	37 (10–62)	23 (10–60)	0.970
Weight categories at listing, kg				
<5	23 (14)	13 (16)	10 (12)	0.544
5–10	29 (18)	13 (16)	16 (20)	
11–25	30 (18)	12 (15)	18 (22)	
26–50	21 (13)	13 (16)	8 (10)	
>50	61 (37)	31 (38)	30 (37)	
Status 1A at listing	145 (88)	71 (87)	74 (90)	0.627
Blood type O	95 (58)	48 (59)	47 (57)	1.000
Female	74 (45)	37 (45)	37 (45)	1.000
Black	43 (26)	23 (28)	20 (24)	0.723
Cardiac diagnosis at listing				
Congenital heart disease	57 (35)	29 (35)	28 (34)	1.000
Cardiomyopathy	96 (59)	48 (59)	48 (59)	
Retransplant	11 (7)	5 (6)	6 (7)	
MCS at listing	54 (33)	27 (33)	27 (33)	1.000
GFR at listing, ml/min/1.73 m^2	77 (53–105)	75 (56–100)	78 (51–109)	0.665
Renal function at listing				
Preserved	120 (73)	61 (74)	59 (72)	0.872
Moderate dysfunction	27 (16)	12 (15)	15 (18)	
Severe dysfunction	17 (10)	9 (11)	8 (10)	
Dialysis at listing	12 (7)	6 (7)	6 (7)	1.000
Public health insurance at listing	88 (54)	45 (55)	43 (52)	0.876

Values are median (25th to 75th percentile) or n (%). The propensity score–matched TCS cohort includes 52 patients supported with the CentriMag-PediMag system (Thoratec, Pleasanton, California), 14 patients supported with the TandemHeart system (CardiacAssist, Pittsburgh, Pennsylvania), 5 patients supported with the Impella system (Abiomed, Danvers, Massachusetts), 5 patients supported with the Rotaflow system (DataScope/Maquet, Rastatt, Germany), and 6 patients supported with various other types of TCS.

Abbreviations as in Table 1.

0.96) despite no significant difference in post-HT survival (HR: 0.41; 95% CI: 0.07 to 2.22). Because CentriMag-PediMag patients represented the single largest group of TCS patients, we performed a secondary analysis examining survival in this subgroup (**Figures 4C and 4D**). Compared with the ECMO cohort, the 52 PS-matched CentriMag-PediMag patients had longer waitlist survival (HR: 0.49; 95% CI: 0.27 to 0.88) and a trend toward longer overall survival (HR: 0.63; 95% CI: 0.36 to 1.10; p = 0.11) despite no significant difference in post-HT survival (HR: 0.29; 95% CI: 0.03 to 2.83). **Figure 5** summarizes the competing outcomes for PS-matched children supported with a TCS device versus ECMO as a bridge to transplant.

DISCUSSION

In this study, we found that: 1) the use of TCS devices in children has risen dramatically over the last 10 years; 2) a variety of TCS device brands are used in children however the CentriMag-PediMag system is the predominant device used in children today; 3) support durations are significantly longer for TCS devices compared with ECMO although important variation exists among TCS devices; and 4) waitlist and overall survival is significantly higher for TCS devices than ECMO after adjusting for patient factors (**Central Illustration**).

Our findings are consistent with recent reports that have documented a rise in the use of TCS devices in children (13,21,26). In the largest multicenter study to date, Lorts et al. (21) examined the outcomes of 49 children supported with TCS devices reported to the PEDIMACS (Pediatric Inter-Agency Mechanically Assisted Circulatory Support) registry. The median duration of support was 12 days with 48% surviving to transplant or recovery, and bleeding was the most common adverse event. However, this study lacked a control group to understand device performance relative to the field's benchmark short-term circulatory support device (ECMO), and lacked power to risk-adjust outcomes or examine individual devices separately. By contrast the present study, with nearly 100 children supported with a TCS device is the largest study to date, demonstrates that support durations for TCS devices are 3-fold longer than support durations achieved for ECMO—especially for the CentriMag-PediMag system—and most importantly, demonstrates for the very first time that patient survival is superior for TCS devices compared with ECMO.

We were somewhat surprised to discover the CentriMag-PediMag system not only was the most commonly used device in U.S. children, but also conferred the longest support durations with a significant survival benefit. It is unclear why this is the case, because other centrifugal flow pumps such as the Rotaflow pump are ostensibly more similar than different. We speculate that the performance advantage may stem from the CentriMag-PediMag's use of magnetic levitation to spin the impeller inside the pump, rather than relying on seals and ball bearings, making it more resistant to wear and tear, heat generation, and pump thrombosis; and the ability of the device to sustain slower rotational speeds to hover at lower flow rates safely (i.e., in the range of 400 to 500 ml/min) without significant hemolysis or

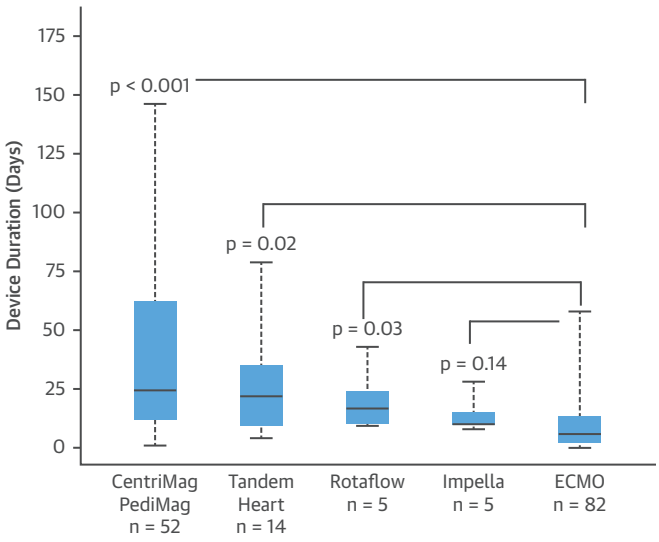
thrombosis (27). These performance characteristics make the pump suitable for even the smallest infants, including newborns with single-ventricle lesions, where bridge-to-transplant outcomes have been especially poor historically (1,28–31).

Our findings have several important implications. First, our findings suggest that the use of TCS VADs has grown considerably over the last 5 years and is now emerging as a new standard of care for short-term VAD therapy in children with end-stage heart failure. With 50 implants in 2015 alone, TCS VADs now represent more than 1 of 4 VADs being implanted in U.S. children today, with no signs yet the growth has started to level off. This growth may be driven in part by disappointment with ECMO for short-term support as well as durable VADs in the smallest children, and by the encouraging early experience with TCS device support as initially reported by Wearden and Maul (32), Morales et al. (33), and others (16).

Second, our findings confirm what many have suspected but found elusive to demonstrate—that TCS VADs afford children a compelling survival advantage over ECMO for bridge to transplant. It is interesting to note that growing use of TCS VADs has resulted in only a modest reduction in ECMO use as a bridge to transplant. We anticipate that ECMO is not likely to disappear anytime soon because it will continue to play a critical role: 1) in the support of children presenting in extremis because of its rapid (percutaneous) deployment capability; 2) in providing full life support (i.e., both biventricular and complete respiratory support when the lungs are too sick to be supported by conventional ventilation alone); and 3) in buying valuable time for potential ventricular recovery in children presenting with new onset LV dysfunction while a diagnosis of acute myocarditis remains a possibility, without committing the child to a sternotomy or ventriculotomy unnecessarily.

Last, our findings suggest that select TCS devices—most notably the CentriMag-PediMag system—have made significant inroads not just as short-term circulatory support devices but also as long-term circulatory support devices in clinical situations where existing (Food and Drug Administration-approved) long-term devices have mixed results (29,30). Indeed, in the Berlin Heart Excor Pediatric experience, children under 5 to 10 kg with complex single-ventricle heart disease had extremely poor survival to transplant (<10%) (29,30). Our findings suggest that this group of smaller children with the highest mortality using currently available durable VADs may stand to benefit the most from repurposing short-term devices to serve as long-term devices as a bridge to transplant. Newer, durable continuous flow, intracorporeal devices are currently being developed for smaller children that may be able to support this population more effectively while also facilitating hospital discharge (34,35). Hospital discharge is not feasible with the current generation of TCS devices (36).

FIGURE 3 Comparison of Support Duration for Each Temporary Circulatory Support Device Relative to Conventional ECMO Among Propensity Score–Matched Patients



The median duration of device support was 3 times longer for temporary circulatory support device patients (19 days) compared with extracorporeal membrane oxygenation (ECMO) patients (6 days; $p < 0.001$). CentriMag-PediMag (Thoratec, Pleasanton, California) patients had the longest support duration (24 days) compared with propensity score–matched ECMO patients (6 days; $p < 0.001$). TandemHeart (CardiacAssist, Pittsburgh, Pennsylvania) patients had the second longest duration (22 days; $p = 0.02$), followed by Rotaflow (DataScope/Maquet, Rastatt, Germany) patients (17 days; $p = 0.03$). Although the median duration of support for Impella (Abiomed, Danvers, Massachusetts) patients was longer than that of ECMO patients, the difference did not reach statistical significance.

STUDY LIMITATIONS. Our study has several limitations related to the retrospective study design. First, this was a retrospective cohort study involving registry data and therefore is susceptible to selection bias. However, OPTN data captures all U.S. subjects listed for HT, is prospectively maintained, and has data quality standards sufficient to rely on UNOS data to allocate solid organs safely to U.S. patients. Residual selection bias by unmeasured confounders is another potential source of selection bias in a PS-matching design. Although it is difficult

FIGURE 4 Comparison of Waitlist Outcome as Well as Post-Heart Transplant and Overall Survival for the PS-Matched Patients to ECMO in the Overall Cohort and the CentriMag-PediMag Cohort

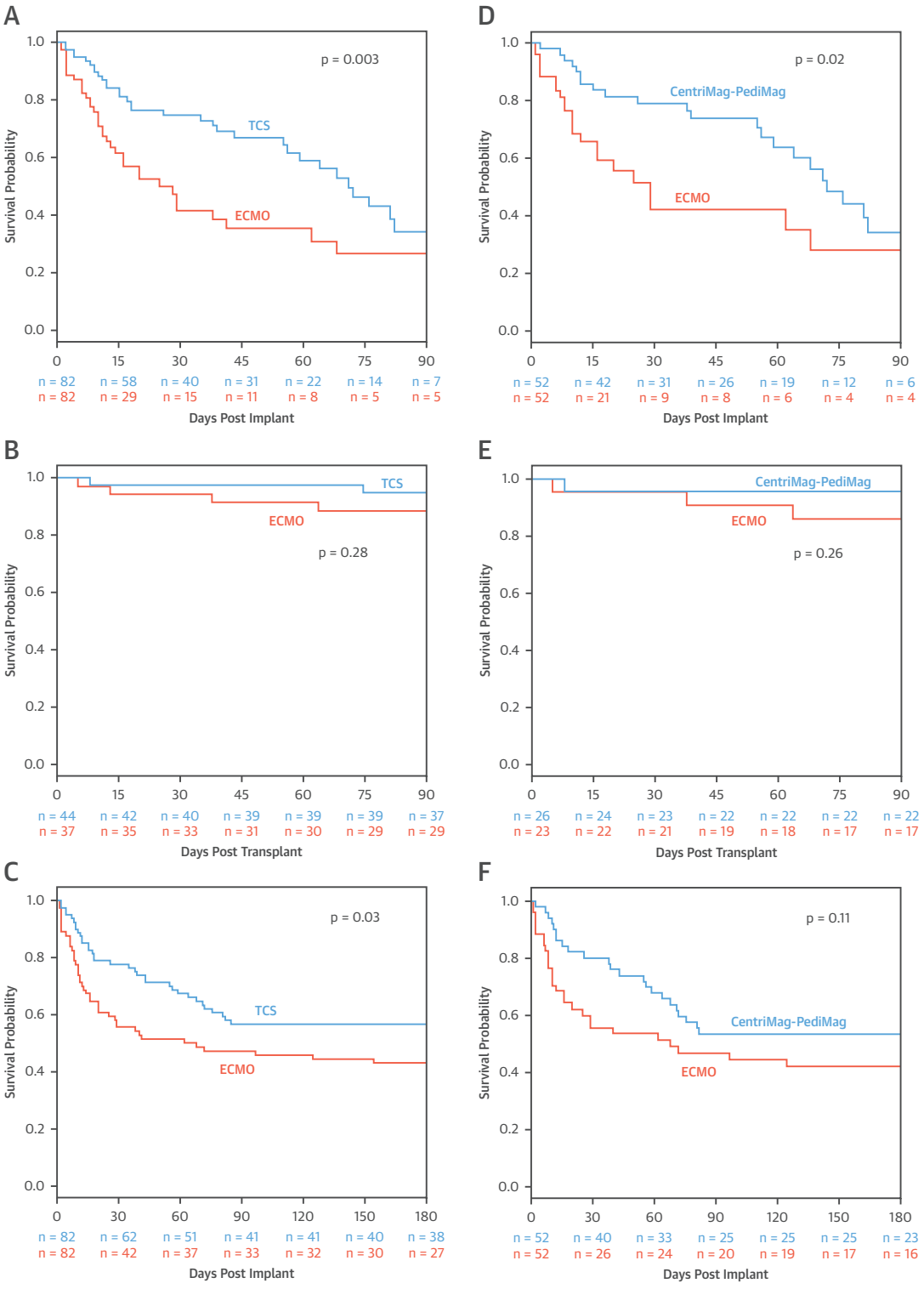


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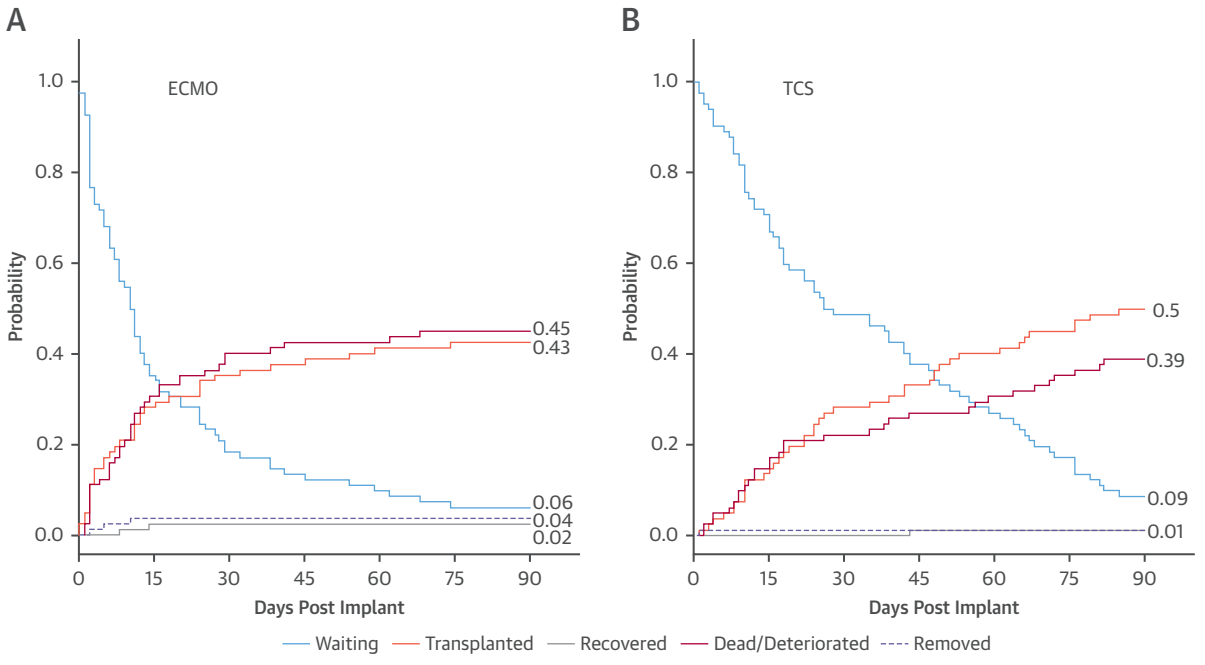
FIGURE 5 Competing Outcomes for PS-Matched Cohort of Children Supported With ECMO and a TCS Device



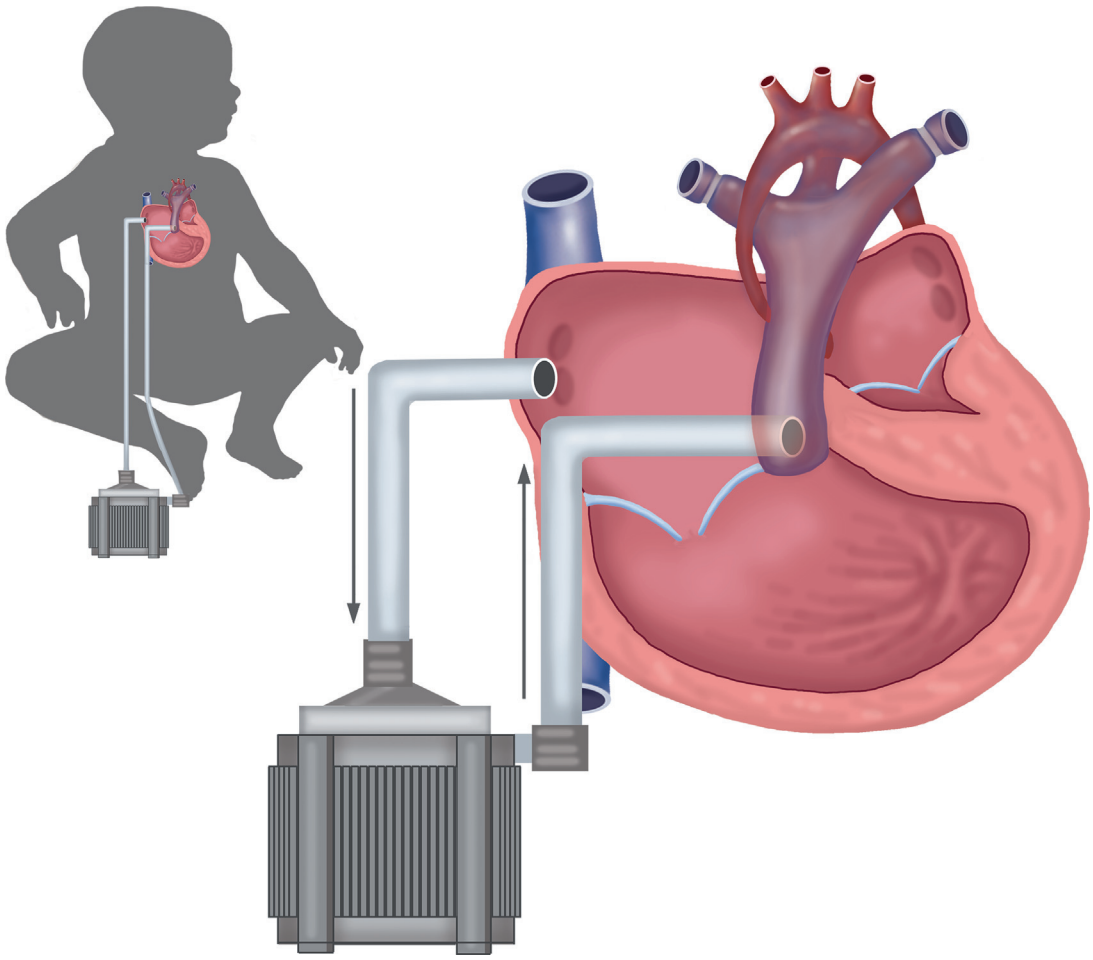
The x-axis represents the time interval from device implant to transplant, death, or recovery. There is a modest reduction in mortality while awaiting heart transplant for children supported with a TCS device (39%) versus an ECMO device (45%) after propensity matching. **(A)** Competing outcomes for the PS-matched ECMO cohort. **(B)** Competing outcomes for the PS-matched TCS cohort. Abbreviations as in Figure 4.

to exclude this possibility altogether, the well-balanced characteristics of the study groups leads us to believe that the effect of residual confounding is not likely to be substantial. Second, the sample size of our cohort was limited, which increases the risk of type II statistical error. However, the present study is the largest TCS study to date and our primary study findings were statistically significant even after adjusting for patient differences using PS matching. Still, we elected not to make comparisons between individual TCS devices (e.g., CentriMag-PediMag vs. Rotaflow) because the number of patients on select device types that could be PS-matched was too small for

FIGURE 4 Continued

(A) Kaplan-Meier survival for the 164 propensity score (PS)–matched temporary circulatory support (TCS) and extracorporeal membrane oxygenation (ECMO) patients from device implant to waitlist removal due to death or deterioration. **(B)** Kaplan-Meier post-heart transplant survival for the PS-matched TCS and ECMO patients from transplant to death. **(C)** Kaplan-Meier overall survival for the 164 PS-matched TCS and ECMO patients from device implant to death inclusive of pre- and post-transplant time periods. **(D)** Kaplan-Meier survival for the 104 PS-matched CentriMag-PediMag (Thoratec, Pleasanton, California) and ECMO patients from device implant to waitlist removal due to death or deterioration. **(E)** Kaplan-Meier post-heart transplant survival for the PS-matched TCS and ECMO patients from transplant to death. **(F)** Kaplan-Meier overall survival for the 104 PS-matched TCS and ECMO patients from device implant to death inclusive of pre- and post-transplant time periods. Children supported with a TCS device had **(A)** longer survival to heart transplant and **(C)** longer overall survival, **(B)** despite similar post-heart transplant survival, compared with a PS-matched cohort of children supported with ECMO. Children supported with the CentriMag-PediMag system had **(D)** longer survival to heart transplant and **(F)** a trend toward longer overall survival, **(E)** with similar post-heart transplant survival, compared with ECMO patients who were PS-matched.

CENTRAL ILLUSTRATION **Temporary Circulatory Support in Children Awaiting Heart Transplant**



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meaningful comparison. Last, our study cannot draw inferences about device safety because UNOS does not capture device-related adverse events. Emerging analysis from the PEDIMACS registry, where adverse event data are collected, will be invaluable for looking at the comparative safely profile of various devices.

CONCLUSIONS

The use of TCS devices in children has risen dramatically in recent years and involves a variety of different devices, although the CentriMag-PediMag system is the predominant TCS VAD used in children for LVAD, RVAD, and BIVAD support. Support durations are significantly longer for TCS devices compared with ECMO, with the longest support durations observed for the CentriMag-PediMag system, leading some centers to repurpose the device for durable support, perhaps in part because of poor outcomes in selected subgroups with existing durable VAD options. Most importantly, there appears to be a demonstrable survival advantage for TCS devices over ECMO, which has long served as the standard for short-term circulatory support in children. Although the optimal role

of TCS VAD use in children is still being defined, continued innovation in TCS care will likely play a critical role in further reducing waitlist mortality, which remains a major problem in children who fail medical therapy.

ADDRESS FOR CORRESPONDENCE: Dr. Vamsi V. Yarlagadda, Division of Pediatric Cardiology, Stanford University, The Lucile Packard Children's Hospital, 750 Welch Road, Suite 305, Palo Alto, California 94304. E-mail: vvy@stanford.edu.

PERSPECTIVES

COMPETENCY IN SYSTEMS-BASED PRACTICE: Compared with ECMO, TCS devices can improve survival increased in children with advanced heart failure awaiting transplantation.

TRANSLATIONAL OUTLOOK: Comparative studies are needed to better characterize the adverse event and safety profiles of the various available TCS devices.

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