Prolonged waitlisting is associated with mortality in extracorporeal membrane oxygenation-supported heart transplantation candidates

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ABSTRACT

Objective: Heart transplantation (HTx) candidates supported with venoarterial extracorporeal membrane oxygenation (ECMO) may be listed at highest status 1 but are at inherent risk for ECMO-related complications. The effect of waitlist time on postlisting survival remains unclear in candidates with ECMO support who are listed using the new allocation system.

Methods: Adult candidates listed with ECMO for a first-time, single-organ HTx from October 18, 2018, to March 21, 2021, in the Scientific Registry of Transplant Recipients database were included and stratified according to waitlist time (≤7 vs >8 days). Postlisting outcomes were compared between cohorts.

Results: Among 175 candidates waitlisted for ≤7 days, 162 (92.6%) underwent HTx whereas 13 (7.4%) died/deteriorated compared with 41 (57.8%) and 21 (29.6%) of the 71 candidates waitlisted for >8 days, respectively (P < .01). Blood type O candidates (odds ratio [OR], 2.94; 95% CI, 1.54-5.61) were more likely to wait >8 days whereas candidates with concurrent intra-aortic balloon pump were less likely (OR, 0.30; 95% CI, 0.10-0.89). Obesity was additionally associated among those listed at status 1 (OR, 2.04; 95% CI, 1.00-4.17). Waitlisting for >8 days was independently associated with 90-day postlisting mortality conditional on survival to day 8 postlisting (hazard ratio, 5.59; 95% CI, 2.59-12.1). Candidates listed at status 1 showed similar trends (hazard ratio, 5.49; 95% CI, 2.39-12.6). There was no significant difference in 90-day post-HTx survival depending on whether a candidate waited for >8 days versus ≤7 days (92.7 vs 92.0%; log rank P = .87).

Conclusions: Among ECMO-supported candidates, obtaining HTx within 1 week of listing might improve overall survival. (JTCVS Open 2022;12:234-54)

In October 2018, the Organ Procurement and Transplantation Network updated its donor heart allocation policy to permit candidates in florid biventricular failure, supported with either venoarterial extracorporeal membrane oxygenation (ECMO) or surgical biventricular assist device, uncontended placement atop the waitlist with wider access to donor organs. This change was prompted by data showing disproportionate waitlist mortality in this cohort under the old allocation systems that permitted hemodynamically stable...
Abbreviations and Acronyms

- BMI = body mass index
- ECMO = extracorporeal membrane oxygenation
- HR = hazard ratio
- HTx = heart transplantation
- IABP = intra-aortic balloon pump
- IQR = interquartile range
- LVAD = left ventricular assist device
- OR = odds ratio
- SRTR = Scientific Registry of Transplant Recipients

Study Definitions

Candidates were stratified according to waitlist time (≤7 vs ≥8 days) with comparison of characteristics at the time of listing. The cutoff of 1 week was chosen because candidates supported with ECMO must be reapproved by the regional review board every 7 days to remain at status 1. The primary end point was composed of death (either post-HTx or waitlist) or waitlist removal because of clinical deterioration, because nearly three-quarters of these patients die within 1 year of delisting.7 Survival time from listing was calculated as the sum of waitlist time and post-HTx survival time; candidates who did not undergo HTx were assigned a post-HTx survival time of 0.

Statistical Analysis

Continuous variables are presented as median (interquartile range [IQR]) and categorical variables are presented as number (percent). After stratification according to waitlist time, baseline demographic characteristics were compared using the Wilcoxon rank sum test for continuous variables and the χ² test or Fisher exact test for categorical variables. The Kaplan–Meier method and log rank tests were used to determine survival differences between groups. Candidates who did not experience the outcome of interest were censored at 90 days postlisting. Variables included in logistic regression and Cox proportional hazards models were selected on the basis of clinical and/or biological relevance. Additionally, collinearity was examined in all models using the variance inflation factor. Results of multivariable analyses are presented as hazard ratio (HR) or odds ratio (OR), where appropriate, with accompanying 95% CI. These analyses included the following:

I) Cox proportional hazards models to examine 90-day postlisting survival conditional on survival to 8 days postlisting, which was performed to determine difference in postlisting outcomes between those who were alive at this point after HTx versus those who were alive at this point on the waitlist;

II) Logistic regression to determine risk factors associated with waitlist time ≥8 days; and

III) A subanalysis of post-HTx survival using Cox proportional hazards models to determine 1) whether differences in postlisting survival were chiefly because of post-HTx or waitlist demise, and 2) if HTx remains a viable exit strategy for candidates waitlisted ≥8 days.

In analysis I, a landmarked analysis was performed to avoid immortal time bias, because, by definition, anyone who survives to ≥8 days of waitlisting has survived the first 7 days. We additionally examined characteristics of candidates who underwent HTx versus died or deteriorated on the waitlist if listed for ≥8 days. All analyses were repeated among candidates listed at status 1 to determine the robustness of observed results. Stata version 17 (StataCorp) was used for all analyses.

RESULTS

Overall Trends

A total of 246 candidates were included with a median waitlist time of 4 days (IQR, 2–9 days; Figure 1, A); patients listed as status 1 (n = 210) had a median waitlist time of 4 days (IQR, 2–7 days; Figure 1, B). In 2018, 4/11 (36.4%) candidates were waitlisted for ≥8 days compared with 11/30 (36.7%) in 2021 (P for trend = .46; Figure 2, A). Among status 1 candidates, 22.2% waited for ≥8 days in 2018 compared with 37.0% in 2021 (P for trend = .15; Figure 2, B).

Baseline Characteristics

Cohorts showed a similar distributions of age, sex, and body mass index (BMI). Candidates who waited for...
≥8 days were more likely to be blood type O (56.3% vs 34.9%; \(P < .01\)) and have elevated creatinine (35.2% vs 22.3%; \(P = .04\)) whereas they were less likely to be concurrently supported by intra-aortic balloon pump (IABP; 7.0% vs 20.0%; \(P = .01\)) or listed at status 1 (67.6% vs 92.6%; \(P < .01\); Table 1). Similar trends were observed among status 1 candidates, with significantly more blood type O (56.3% vs 36.4%; \(P < .01\)) and previous smokers (35.4% vs 21.0%; \(P = .04\)) among those waitlisted for ≥8 days with less with concurrent IABP support (6.4% vs 19.1%; \(P = .03\); Table E1).

Multivariable logistic regression showed blood type O (OR, 2.94; 95% CI, 1.54-5.61) to be independently associated with increased likelihood of waitlist time ≥8 days; concurrent IABP support (OR, 0.30; 95% CI, 0.10-0.89) and status 1 listing (OR, 0.12; 95% CI, 0.05-0.30) were associated with decreased likelihood of waitlist time ≥8 days (Table 2). Among status 1 candidates, blood type O (OR, 2.15; 95% CI, 1.08-4.24) and obesity (OR, 2.04; 95% CI, 1.00-4.17) remained independently associated with prolonged waitlisting (Table E2).

Waitlist Outcomes and Postlisting Survival

Among candidates waitlisted for ≥8 days, 57.8% ultimately received a transplant, whereas 29.6% died or deteriorated on the waitlist. However, 92.6% of candidates waitlisted ≤7 days received a transplant whereas only 7.4% died or deteriorated (\(P < .01\); Figure 3, A). Of status 1 candidates waitlisted for ≤7 days 93.8% received a transplant whereas 6.2% died or deteriorated; 56.3% of those who waited for ≥8 days received a transplant and 29.2% died or deteriorated (\(P < .01\); Figure 3, B). Overall, 9 (3.7%) candidates were removed because of recovery or other causes; all of these candidates were listed for ≥8 days. The percentage of candidates removed from the waitlist because of HTx was highest when listed for ≤4 days at 97.6% (Figure E1).

Two of 162 (1.2%) candidates who received a transplant within 7 days of listing died shortly after HTx. Ninety-day postlisting survival was estimated to be 70.4% (95% CI, 58.3%-79.6%) if a candidate remained waitlisted at 8 days compared with 93.7% (95% CI, 88.7%-96.6%) if the candidate received a transplant (Figure 4, A). Multivariable Cox proportional hazards analysis showed an independent association between waitlisting ≥8 days and 90-day mortality (HR, 5.59; 95% CI, 2.59-12.1; Table 3). These results were replicated on analysis of status 1 candidates alone (HR, 5.49; 95% CI, 2.39-12.6; Table E3; Figure 4, B).

Recipient Characteristics

Forty-one recipients underwent HTx after listing for ≥8 days compared with 162 at ≤7 days. Recipients who received a transplant at ≥8 days were younger (44 vs 53 years; \(P = .04\)) and less likely to be supported with ECMO at HTx (63.4% vs 95.7%; \(P < .01\)) or mechanically ventilated (7.35% vs 29.0%; \(P < .01\)) whereas more often blood type O (53.7% vs 35.2%; \(P = .03\)) and more likely to be supported with durable left ventricular assist device (LVAD; 12.2% vs 0.6%; \(P < .01\); Table E4). Donors were similarly likely to be blood type O and otherwise showed similar characteristics. There were no significant differences in ischemic time or distance from recipient to donor. At 90 days post-HTx, 92.0% of recipients listed for ≤7 days were alive compared with 92.7% if listed for ≥8 days (log rank \(P = .87\); Figure E2, A).

Among those listed at status 1, those who underwent HTx at ≥8 days of listing were younger (39 vs 53 years; \(P = .04\)) and less likely to be mechanically ventilated (7.4% vs 29.6%; \(P = .02\)) or supported with ECMO (70.4% vs 96.7%; \(P < .01\)) but more likely to be supported with...
durable LVAD (7.4% vs 0%; \( P = .02 \)) at the time of transplantation (Table E5). There was no significant difference in donor or operative characteristics. For patients listed as status 1, 90-day post-HTx survival was 92.6% among those who waited for ≥8 days compared with 91.4% among those who waited for ≤7 days (log rank \( P = .83 \); Figure E2, B).

Compared with candidates who were waitlisted for ≥8 days and underwent HTx, those who died or deteriorated were older (58 vs 44 years; \( P < .01 \)) and showed greater atherosclerotic burden, indicated by a greater prevalence of ischemic heart disease (57.1% vs 19.5%; \( P < .01 \)), diabetes (47.6% vs 17.1%; \( P = .01 \)), and cerebrovascular accident (23.8% vs 2.4%; \( P = .01 \); Table E6). Among those listed at status 1, a larger proportion of those who died showed ischemic heart failure etiology (57.1% vs 25.9%; \( P = .049 \)). The study design and findings are represented in Figure 5.

**DISCUSSION**

In the present study we examined the relationship between prolonged waitlist time and postlisting survival and had 4 key findings. First, waitlist time >1 week while listed with ECMO support was independently associated with worse postlisting survival. Second, blood type O, a nonmodifiable risk factor, was associated with prolonged waitlist
time. Third, waitlist time >1 week did not compromise the efficacy of HTx as an exit strategy. Fourth, after being waitlisted for >1 week, candidates who then die or deteriorate showed characteristics associated with acquired heart disease. Moreover, the relationship between waitlist time and postlisting survival remained present on examination of status 1 candidates alone. Taken together, these data suggest that undergoing prompt HTx is of high importance in candidates listed with ECMO support, although young candidates without a large chronic disease burden who are clinically stable can be maintained on the waitlist if they cannot receive a transplant within the first week.

Using previous allocation systems, it has been noted that inability to acquire a suitable heart for transplantation among ECMO-supported candidates in a timely fashion is associated with poor postlisting survival. Ivey-Miranda and colleagues analyzed 712 candidates supported with ECMO and showed postlisting survival at 1 year to be.

### TABLE 1. Candidate characteristics

|                          | ≤7 Days (n = 175) | ≥8 Days (n = 71) | P value |
|--------------------------|------------------|-----------------|---------|
| Age, y                   | 53 (39-60)       | 51 (32-60)      | .42     |
| Female sex               | 46 (26.3)        | 22 (31.0)       | .46     |
| BMI                      | 27.3 (24.2-31.6) | 28.0 (24.6-33.5) | .39     |
| Blood type O             | 61 (34.9)        | 40 (56.3)       | <.01    |
| Ethnicity                |                  |                 |         |
| White                    | 123 (70.3)       | 44 (62.0)       | .43     |
| Black                    | 25 (14.3)        | 12 (16.9)       | .69     |
| Other                    | 27 (15.4)        | 15 (21.1)       |         |
| Region                   |                  |                 | .04     |
| Northeast                | 57 (32.6)        | 14 (19.7)       |         |
| Southeast                | 45 (25.7)        | 30 (24.3)       |         |
| Midwest                  | 40 (22.9)        | 17 (23.9)       |         |
| West                     | 33 (18.9)        | 10 (14.1)       |         |
| Private insurance        | 103 (58.9)       | 42 (59.2)       | .97     |
| Heart failure etiology   |                  |                 | .57     |
| Nonischemic              | 120 (68.6)       | 46 (64.8)       |         |
| Ischemic                 | 55 (31.4)        | 25 (35.2)       |         |
| Medical history          |                  |                 |         |
| Diabetes                 | 34 (19.5)        | 18 (25.4)       | .31     |
| CVA                      | 11 (6.4)         | 6 (8.5)         | .57     |
| ICD                      | 58 (33.1)        | 26 (36.6)       | .60     |
| Smoking                  | 40 (22.9)        | 24 (33.8)       | .08     |
| Previous cardiac surgery | 41 (23.4)        | 19 (26.8)       | .58     |
| Inotrope-dependent       | 96 (54.9)        | 36 (50.7)       | .55     |
| Ventilator-dependent     | 58 (33.1)        | 18 (25.4)       | .23     |
| Creatinine ≥1.5 mg/dL    | 39 (22.3)        | 25 (35.2)       | .04     |
| Concurrent MCS           |                  |                 |         |
| IABP                     | 35 (20.0)        | 5 (7.0)         | .01     |
| Microaxial LVAD          | 25 (14.3)        | 8 (11.3)        | .61     |
| Durable LVAD             | 3 (1.7)          | 3 (4.2)         | .25     |
| Listing status           |                  |                 | <.01    |
| 1                        | 162 (92.6)       | 48 (67.6)       |         |
| 2                        | 9 (5.1)          | 6 (8.5)         |         |
| 3                        | 1 (0.6)          | 4 (5.6)         |         |
| 4                        | 0                | 4 (5.6)         |         |
| 5                        | 1 (0.6)          | 5 (7.0)         |         |
| 7                        | 2 (1.1)          | 4 (5.6)         |         |

Continuous variables are presented as median (interquartile range) and categorical variables are presented as n (%). Statistical significant P-values were shown in bold. BMI, Body mass index; CVA, cerebrovascular accident; ICD, implantable cardioverter-defibrillator; MCS, mechanical circulatory support; IABP, intra-aortic balloon pump; LVAD, left ventricular assist device. *Northeast: UNOS regions 1, 2, and 9; Southeast: UNOS regions 3, 4, and 11; Midwest: UNOS regions 7, 8, and 10; and West: UNOS regions 5 and 6.
TABLE 2. Risk factors for prolonged waitlist time (≥8 days)

|                        | Univariable |         | Multivariable |         |
|------------------------|-------------|---------|--------------|---------|
|                        | OR          | P value | OR           | P value |
| Age, y                 | 0.99 (0.97-1.01) | .35     | 0.98 (0.96-1.00) | .08     |
| Female sex             | 1.26 (0.69-2.31) | .46     | 1.46 (0.73-2.92) | .28     |
| Obese                  | 1.45 (0.82-2.56) | .20     | 1.93 (0.99-3.74) | .052    |
| Blood type O           | 2.41 (1.37-4.23) | <.01    | 2.94 (1.54-5.61) | <.01    |
| White ethnicity        | 0.69 (0.39-1.23) | .21     |               |         |
| Region*                |             |         |               |         |
| Northeast              | Ref.        | –       | Ref.          | –       |
| Southeast              | 2.71 (1.29-5.72) | <.01    | 1.91 (0.82-4.42) | .13     |
| Midwest                | 1.73 (0.77-3.91) | .19     | 1.64 (0.68-4.00) | .27     |
| West                   | 1.23 (0.49-3.09) | .65     | 1.16 (0.43-3.16) | .77     |
| Private insurance      | 1.01 (0.58-1.77) | .97     |               |         |
| Ischemic HF etiology   | 1.19 (0.66-2.12) | .57     |               |         |
| Medical history        |             |         |               |         |
| Diabetes               | 1.40 (0.73-2.69) | .31     |               |         |
| CVA                    | 1.35 (0.48-3.81) | .57     |               |         |
| ICD                    | 1.17 (0.65-2.07) | .60     |               |         |
| Smoking                | 1.72 (0.94-3.16) | .08     |               |         |
| Previous cardiac surgery | 1.19 (0.64-2.24) | .58     |               |         |
| Inotrope-dependent     | 0.85 (0.49-1.47) | .55     |               |         |
| Ventilator-dependent   | 0.69 (0.37-1.27) | .23     |               |         |
| Creatinine ≥1.5 mg/dL  | 1.90 (1.04-3.46) | .04     |               |         |
| Concurrent MCS         |             |         |               |         |
| IABP                   | 0.30 (0.11-0.81) | .02     | 0.30 (0.10-0.89) | .03     |
| Microaxial LVAD        | 0.80 (0.34-1.87) | .61     |               |         |
| Durable LVAD           | 2.53 (0.50-12.8) | .55     |               |         |
| Listing at status 1    | 0.17 (0.08-0.36) | <.01    | 0.12 (0.05-0.30) | <.01    |

Statistical significant P-values were shown in bold. OR, Odds ratio; HF, heart failure; CVA, cerebrovascular accident; ICD, implantable cardioverter-defibrillator; MCS, mechanical circulatory support; IABP, intra-aortic balloon pump; LVAD, left ventricular assist device. *Northeast: UNOS regions 1, 2, and 9; Southeast: UNOS regions 3, 4, and 11; Midwest: UNOS regions 7, 8, and 10; and West: UNOS regions 5 and 6.

FIGURE 3. Bar charts showing the percentage of candidates removed from the waitlist because of heart transplantation (HTx), death/deterioration, or other causes stratified according to waitlist time. A, The entire cohort, and (B) status 1 candidates only. χ² P is < .01 in both graphs.
22.5% if the candidate did not undergo HTx compared with 73.4% if they did. In this same analysis, it was shown that longer time on the waitlist is associated with worse post-HTx survival on the order of a 2% increase per day waitlisted. Despite higher rates of post-HTx mortality among ECMO-supported recipients, Singh and colleagues showed that the survival benefit gained from HTx compared with continued waitlisting increases among sicker candidates. In the present analysis, we were unable to detect a significant difference in post-HTx mortality among recipients.
with a prolonged waitlist time, with excellent post-HTx survival among those listed for ≤7 days (92.0% and those listed for ≥8 days (92.7%). When interpreting this information, there is a caveat, however, in that selection bias might be present in considering candidates who survived to HTx after listing for ≥8 days. When examining the clinical characteristics of this population compared with those listed for ≤7 days, we noticed these candidates were less likely to be ECMO-dependent at the time of HTx and more likely to be durable LVAD-dependent, leading one to consider the role of durable LVAD as a feasible bridge from ECMO to HTx.

In a recent analysis of combined SRTR and Interagency Registry for Mechanically Assisted Circulatory Support databases, DeFilippis and colleagues investigated survival among candidates bridged with ECMO to LVAD versus HTx. They showed post-ECMO to HTx survival of 70.7% at 1 year, 66.6% at 2 years, and 61.8% at 5 years compared with 69.2%, 62.6%, and 56.5% at 1, 2, and 5 years, respectively, among those bridged to LVAD. However, this analysis did not separate post-HTx outcomes according to allocation system. Published data demonstrate post-HTx survival rates of approximately 90% in those bridged directly to HTx and might thus obfuscate this equivalency in the current era. From this information, the question does then arise of whether temporary support candidates are currently transplanted too fast without consideration of transition to durable support. In a recent analysis of the SRTR database, Topkara and colleagues showed a significant decrease in rate of waitlist recovery using the new system in this population, suggesting an inadequate period for improvement while receiving temporary support. It appears that candidates listed with durable LVAD also have shorter waitlist time using the current allocation system, although their post-HTx outcomes might be suffering. Undoubtedly, further investigation is required in this area.

Among the total cohort, we noticed blood type O to be independently associated with prolonged waitlist time, whereas obesity emerged as an additional predictor among those listed at status 1. Regarding blood type, it has been recognized that type O candidates have longer waitlist time, at least in part because of the biology of donor organs they can accept. This phenomenon is intriguing when considering the population restricted to status 1 candidates, as per United Network for Organ Sharing donor heart allocation policies, type O hearts are first offered to status 1 candidates of a primary blood type match within 500 nautical miles. Interestingly, there was no difference in the proportion of type O donors among those who received a transplant within 7 days versus ≥8 days without a notable difference in donor quality, although a larger proportion of candidates who received a transplant ≥8 days were blood type O. This likely indicates that several type O donor hearts were passed on by type O candidates. First, this could represent a subconscious bias in which type O candidates supported with ECMO tend to be listed earlier in their

FIGURE 5. A summary of the study’s methodology, findings, and implications. ECMO, Extracorporeal membrane oxygenation; SRTR, Scientific Registry of Transplant Recipients; CI, confidence intervals; HTx, heart transplant; HR, hazard ratio.
cardiogenic shock process because of known difficulties obtaining HTx in this population.14,16 This might also be reflective of true differences in pathophysiology, because type O candidates are less likely to be afflicted by ischemic heart disease.17 Although listed for HTx, transplant teams might opt to monitor the patient’s status closely while still having the option of urgent HTx if needed as opposed to waiting for failure to recover and then listing. Regarding concurrent IABP use, Nishi and colleagues18 recently examined concurrent IABP use in ECMO in a large Japanese national database and showed significant decreases in post-ECMO mortality. They reported significantly higher rates of concurrent IABP use in large-scale teaching institutions, although in the United States, data documenting the correlation between center volume and advanced ECMO management strategies are sparse.

We additionally noticed an association between obesity and prolonged waitlist time among candidates listed at status 1. In a recently published study, Chouairi and colleagues19 examined the relationship between obesity and HTx outcomes. In this analysis, they showed a dose-dependent decrease in the hazard of undergoing HTx as BMI increased, from 0.83 (95% CI, 0.81-0.85) among those with BMI from 25 to 29.9 to 0.42 (95% CI, 0.36-0.49) among those with a BMI from 40 to 55. This likely represents difficulty in procuring organs of appropriate size match, because donor BMI was noted to be a mean of 26.9 in 2020. In our analysis, mean donor BMI was 28.2, which points toward difficulty obtaining hearts from adequately sized donors as the likely etiology of the increased waitlist time.

This study has several limitations inherent to its design. First, the study was retrospective in nature. Second, although the United Network for Organ Sharing database contains >500 variables, data are collected primarily at the time of listing and HTx, without update during listing.

### TABLE 3. Relationship between waitlist ≥8 days and postlisting death or deterioration, landmarked at 8 days

|                      | Univariable HR (95% CI) | P value | Multivariable HR (95% CI) | P value |
|----------------------|-------------------------|---------|---------------------------|---------|
| Waitlist ≥8 d        | 5.47 (2.58-11.6)        | <.01    | 5.59 (2.59-12.1)          | <.01    |
| Age, y               | 1.04 (1.01-1.07)        | .01     | 1.04 (1.01-1.08)          | <.01    |
| Female gender        | 1.45 (0.69-3.02)        | .33     |                           |         |
| Obese                | 2.32 (1.14-4.70)        | .02     | 1.83 (0.90-3.74)          | .10     |
| Blood type O         | 2.29 (1.11-4.72)        | .03     |                           |         |
| White ethnicity      | 0.62 (0.30-1.28)        | .20     |                           |         |
| Region               |                         |         |                           |         |
| Northeast – Referent | –                       | .01     |                           |         |
| Southeast            | 2.55 (0.90-7.23)        | .08     |                           |         |
| Midwest              | 2.14 (0.70-6.54)        | .18     |                           |         |
| West                 | 2.15 (0.66-7.04)        | .21     |                           |         |
| Private insurance    | 0.68 (0.34-1.38)        | .29     |                           |         |
| Ischemic HF etiology | 2.19 (1.08-4.44)        | .03     |                           |         |
| Medical history      |                         |         |                           |         |
| Diabetes             | 2.53 (1.21-5.29)        | .01     |                           |         |
| CVA                  | 3.09 (1.18-8.08)        | .02     |                           |         |
| ICD                  | 1.41 (0.69-2.89)        | .34     |                           |         |
| Smoking              | 2.23 (1.09-4.56)        | .03     |                           |         |
| Previous cardiac surgery | 1.79 (0.86-3.73) | .12     |                           |         |
| Inotrope-dependent   | 0.83 (0.41-1.68)        | .60     |                           |         |
| Ventilator-dependent | 1.13 (0.53-2.41)        | .74     | 1.18 (0.55-2.52)          | .67     |
| Creatinine ≥1.5 mg/dL| 1.97 (0.95-4.05)        | .07     | 1.33 (0.64-2.77)          | .45     |
| Concurrent MCS       |                         |         |                           |         |
| IABP                 | 0.56 (0.17-1.83)        | .34     |                           |         |
| Microaxial LVAD      | 1.78 (0.73-4.35)        | .20     |                           |         |
| Durable LVAD         | –                       |         |                           |         |
| Listing at status 1  | 0.67 (0.28-1.64)        | .38     |                           |         |

Statistical significant P-values were shown in bold. HR, Hazard ratio; CI, confidence intervals; HF, heart failure; CVA, cerebrovascular accident; ICD, implantable cardioverter-defibrillator; MCS, mechanical circulatory support; IABP, intra-aortic balloon pump; LVAD, left ventricular assist device. *Northeast: UNOS regions 1, 2, and 9; Southeast: UNOS regions 3, 4, and 11; Midwest: UNOS regions 7, 8, and 10; and West: UNOS regions 5 and 6.
It has been shown that a candidate’s risk can change rapidly. Moreover, important variables that might be indicative of a patient’s physiologic status, such as lactate, are not available. Third, the database does not contain granular information surrounding the reason to delist a candidate for other reasons or continue additional support, such as IABP, in those listed for a prolonged period, thus limiting conclusions regarding candidates listed for ≥8 days. Additionally, it should be noted that ECMO is primarily a therapy for those in biventricular failure as opposed to left heart failure, and the decision to pursue ECMO in these patients is highly individualized. Fourth, because the time-points at which data are collected, we were unable to assess the situation surrounding the escalation to ECMO support, such as patients who begin ECMO support in the setting of cardiopulmonary arrest. Fifth, non-status 1 candidates were included to represent the entirety of the candidate pool, with analyses then restricted to status 1 candidates, because of the sample size of the current analysis.

CONCLUSIONS

Although candidates supported with ECMO are listed at status 1 in the new donor heart allocation system, a substantial portion are waitlisted for ≥8 days. Those who do not undergo HTx within the first week after listing are at increased risk of subsequent waitlist demise but show adequate post-HTx survival. Further investigation into optimal bridging strategies of candidates who cannot immediately undergo HTx is warranted.

Webcast

You can watch a Webcast of this AATS meeting presentation by going to: https://www.aats.org/resources/1329.

Conflict of Interest Statement

The authors reported no conflicts of interest. The Journal policy requires editors and reviewers to disclose conflicts of interest and to decline handling or reviewing manuscripts for which they may have a conflict of interest. The editors and reviewers of this article have no conflicts of interest.

References

1. OPTN/UNOS Thoracic Organ Transplantation Committee. Proposal to modify the adult heart allocation system. Accessed April 22, 2022. https://optn.transplant.hrsa.gov/media/2006/thoracic_brief_201612.pdf

2. Wever-Pinzon O, Drakos SG, Kifoury AG, Nativi JN, Gilbert EM, Everitt M, et al. Morbidity and mortality in heart transplant candidates supported with mechanical circulatory support is reappraisal of the current United Network for Organ Sharing thoracic organ allocation policy justified? Circulation. 2013;127:452-62. https://doi.org/10.1161/CIRCULATIONAHA.112.100123

3. Gonzalez MH, Acharya D, Lee S, Leacche M, Boeve T, Manandhar-Shrestha N, et al. Improved survival after heart transplantation in patients bridged with extracorporeal membrane oxygenation in the new allocation system. J Heart Lung Transplant. 2021;40:149-57. https://doi.org/10.1016/J.HeartLun.2020.11.004

4. Nordan T, Critisinelis AC, Maharokshian SH, Kapur NK, Thayer KL, Chen FY, et al. Bridging with extracorporeal membrane oxygenation under the new heart allocation system: a United Network for Organ Sharing Database analysis. Circ Heart Fail. 2021;14:e1807966. https://doi.org/10.1161/CIRCHEARTFAI-LURE.120.007966

5. Goff RR, Uccellini K, Lindblad K, Hall S, Davies R, Farr M, et al. A change of heart: preliminary results of the US 2018 adult heart allocation revision. Am J Transplant. 2020;20:2781-90. https://doi.org/10.1111/AJt.16010

6. Eckman PM, Katz JN, el Banayosy A, Bohula EA, Sun B, van Diepen S. Venous arterial extracorporeal membrane oxygenation for cardiogenic shock: an introduction for the busy clinician. Circulation. 2019;140:2019-37. https://doi.org/10.1161/CIRCULATIONAHA.119.034512

7. Vanderpuyyn C, Graham DA, Almond CS, Blume ED, Milliren CE, Singh TP. Survival in patients removed from the heart transplant waiting list before receiving a transplant. J Heart Lung Transplant. 2014;33:261-9. https://doi.org/10.1016/J.HeartLun.2014.12.010

8. Ivey-Miranda JB, Maulson C, Farrerro-Torres M, Griffin M, Posada-Martinez EL, Testani JM, et al. Risk stratification of patients listed for heart transplantation while supported with extracorporeal membrane oxygenation. J Thorac Cardiovasc Surg. Published online May 29, 2021 [Epub ahead of print]. https://doi.org/10.1053/j.jtcvs.2021.05.032

9. Fukuhara S, Takeda K, Kurlansky PA, Naka Y, Takayama H. Extracorporeal membrane oxygenation as a direct bridge to heart transplantation in adults. J Thorac Cardiovasc Surg. 2018;155:1607-18.e6. https://doi.org/10.1016/J.Jtcvs.2017.10.152

10. Singh TP, Milliren CE, Almond CS, Graham D. Survival benefit from transplantation in patients listed for heart transplantation in the United States. J Am Coll Cardiol. 2014;63:1169-78. https://doi.org/10.1016/J.JACC.2013.11.045

11. DeFilippis EM, Clerkin K, Truby LK, Francke M, Fried J, Masoumi A, et al. ECMO as a bridge to left ventricular assist device or heart transplantation. JACC Heart Fail. 2021;9:281-9. https://doi.org/10.1016/J.JCHeF.2020.12.012

12. Topkara VK, Sayer GT, Clerkin KJ, Wever-Pinzon O, Takeda K, Takayama H, et al. Recovery with temporary mechanical circulatory support while waitlisted for heart transplantation. J Am Coll Cardiol. 2022;79:900-13. https://doi.org/10.1016/J.Jacc.2021.12.022

13. Nordan T, Critisinelis AC, Orteleva J, Kiernan MS, Vest A, DeNoefrio D, et al. durable left ventricular assist device as a bridge to heart transplantation under the new donor heart allocation system. ASAHO J. 2022;66:890-9. https://doi.org/10.1097/MAT.0000000000001599

14. Ando M, Takeda K, Kurlansky PA, Garan AR, Topkara VK, Yuzefpolskaya M, et al. Association between recipient blood type and heart transplantation outcomes in the United States. J Heart Lung Transplant. 2020;39:363-70. https://doi.org/10.1016/J.HeartLun.2019.12.006

15. OPTN. OPTN policies effective as of April 11, 2022 [COVID19]. Accessed April 22, 2022. https://optn.transplant.hrsa.gov/media/2019/04/Optn_policies.pdf

16. Goldstein BA, Thomas L, Zaroff JG, Nguyen J, Menza R, Khush KK. Assessment of heart transplant waitlist time and pre- and post-transplant failure: a mixed methods approach. Epidemiology. 2016;27:469-76. https://doi.org/10.1097/ede.0000000000000472

17. He M, Wolpin B, Rexrode K, Masoumi A, Ehrlich JD, Hu FB, et al. ABO blood group and risk of coronary heart disease in two prospective cohort studies. Arterioscler Thromb Vasc Biol. 2012;32:2314-20. https://doi.org/10.1161/ATVB.AHA.112.248757

18. Nishi T, Ishii M, Tsujita K, Okamoto H, Kato S, Nakai M, et al. Outcomes of venoarterial extracorporeal membrane oxygenation plus intra-aortic balloon pumping for treatment of acute myocardial infarction complicated by cardiogenic shock. J Am Heart Assoc. 2022;11:e023713. https://doi.org/10.1161/JAHA.121.023713
19. Chouairi F, Milner A, Sen S, Guha A, Stewart J, Jastreboff AM, et al. Impact of obesity on heart transplantation outcomes. J Am Heart Assoc. 2021;10:e021346. https://doi.org/10.1161/JAHA.121.021346.

20. Blackstone EH, Rajeswaran J, Cruz VB, Hsich EM, Kopriwanac M, Smedira NG, et al. Continuously updated estimation of heart transplant waitlist mortality. J Am Coll Cardiol. 2018;72:650-9. https://doi.org/10.1016/J.JACC.2018.05.045

Key Words: heart transplantation, allocation system, prolonged waitlisting

Discussion

Presenter: Dr Masashi Kawabori

Dr Leora Yarboro (Charlottesville, Va). Thank you very much and congratulations. That was an excellent presentation. I have received honoraria from Abbot and Medtronic, neither of which is related to my discussion today. The heart transplant allocation change in 2018 has dramatically affected how we care for patients awaiting heart transplant. There’s been a dramatic shift toward the increased use of temporary circulatory supports such as ECMO in these populations. In your talk today, you demonstrate a decrease in postlisting survival among those patients who were supported for eight days or longer with a high percentage of those patients not progressing to transplant. In this, I have 3 questions for you. The first is, in these data, you showed that a third of the transplant patients—a third of the patients fall into the high-risk category of having to wait more than 8 days from transplant. Do you foresee that this time will get longer as more patients are supported on ECMO pretransplant? And if so, what strategies do you think we can use to mitigate these complications?

Dr Masashi Kawabori (Boston, Mass). Thank you for comments, Dr Yarboro. To answer this question, I think, as shown in the slide, I think there’s improvement room for these issues because, number 1, there’s more than one-third of patients, a lot of patients, are in the high-risk group. And we know what the issue is, prolonged waitlisting. And now, we know that if we could transplant the patient within 7 days or if we could use balloon pump, which is a protective factor, which will help transplant these patients earlier.

Dr Yarboro. Thank you. The second question is, your finding of increased wait time for those patients with the blood group O is consistent with our previous work showing the same thing, in the durable LVAD population. Given that these patients are less likely to progress to transplant, do you think there needs to be a further change in how we allocate organs, or should we be managing these patients who are at disadvantaged from their blood group differently?

Dr Kawabori. Absolutely. In my research group, we do run multiple UNOS analyses. And then, one of the topics—one of the other topics we have is blood type O transplantation under the new allocation system, which our surgical fellow, Dr Eapen, will present today at rapid-fire oral today. I don’t want to steal her thunder. However, long story short, there is—so blood type O recipient could only receive type O donors. However, only 75% of donor O heart are allocated to O recipients. So, there’s 25% of patient donor O hearts, which is leaking out to type A, 15%, and type B, 10%. So, if we could potentially make some allocation algorithm changes, that might help save some of the blood type O recipients.

Dr Yarboro. Thank you. And finally, we have found de-conditioning to be a significant problem for our patients who are awaiting transplant with mechanical support. And were you able to identify any data that were related to cannulation strategy and success in terms of transitioning them to transplant?

Dr Kawabori. That is one of the limitations of our study, the UNOS database data of granularity. So UNOS data do not have the cannulation strategy. So, I think the ELSO database, those have the cannulation site. So, I think studies using the ELSO database will help understand those clinical questions.

Dr Yarboro. Thank you.

Dr Kawabori. Thank you.

Dr Yarboro. And the follow-up to that is, what is your center-specific approach to cannulation for patients who might be blood type O? Is it used any differently, or do you have any thoughts to that?

Dr Kawabori. In our centers, we basically do femoral cannulations. And if the patient does not look optimized enough for transplant, then either we use [inaudible] 55 or bridge with surgical bypass.

Dr Yarboro. Thank you.

Dr Kawabori. Thank you.

Dr Yarboro. Congratulations.

Dr Kawabori. Thank you.

Dr Scott Silvestry (Orlando, Fla). No disclosures for this. So, the question is—2 questions, short questions. First is, you need to look at whether this is acute ECMO or chronic ECMO. These patients who decompensate and then get transplanted or are these patients who are chronic, who slide into ECMO and ECMO is used, and you can get that by looking at the time from listing to actual ECMO. And the date is in the SRTR, so that you can tell patients who were listed who get ECMO as opposed to patients who were listed with ECMO, which is a very important difference. My question to you is we have these data—and then I’ll ask the question. So what? What do you do
differently? What is the actionable item? Is it the patients—the sick patients who don’t get transplanted because they’re not really ready for transplant or is it the doctors? They’re picking and choosing the hearts that they want. They’re not willing to take a 50-year-old heart for a 30-year-old who’s receiving ECMO. What is the factor? And the reality is, it’s probably variable in different places, but we wanted on the committee ECMO 7 days only. And we didn’t want to renew because at some point, as Donna Mancini said, “ECMO becomes a chronic choice because there’s a game advantage of transplants.”

**Dr Kawabori.** I think that’s a very good point. In the UNOS database it doesn’t have data on how many days were there on ECMO prior to this date. So, there is acute and also chronic ECMO patients, which cannot be captured from these data. And I understand that the ECMO duration is 1 of the factors, so I totally agree with you that ECMO >7 days might be overused.
FIGURE E1. Bar charts showing reasons for waitlist removal as days on the waitlist increase. A, One versus ≥ 2 days; (B) ≤ 2 versus ≥ 3 days; (C) ≤ 3 versus ≥ 4 days; (D) ≤ 4 versus ≥ 5 days; (E) ≤ 5 versus ≥ 6 days; and (F) ≤ 6 versus ≥ 7 days. HTx, Heart transplantation.
FIGURE E2. Kaplan–Meier curves showing post-HTx survival stratified according to listing time (A) cohortwide (adjusted HR, 1.13; 95% CI, 0.32-4.05) and (B) among candidates listed at status 1 (adjusted HR, 1.08; 95% CI, 0.24-4.87). CI, Confidence intervals.
TABLE E1. Candidate characteristics, status 1 only

|                         | ≤7 Days (n = 162) | ≥8 Days (n = 48) | P value |
|-------------------------|-------------------|-----------------|---------|
| Age, y                  | 53 (38-60)        | 49 (32-58)      | .18     |
| Female sex              | 44 (27.2)         | 16 (33.3)       | .41     |
| BMI                     | 27.4 (24.1-31.7)  | 30.0 (24.5-33.3) | .15     |
| Blood type O            | 59 (36.4)         | 27 (56.3)       | .01     |
| Ethnicity               |                   |                 | .74     |
| White                   | 117 (72.2)        | 32 (66.7)       |         |
| Black                   | 21 (13.0)         | 8 (16.7)        |         |
| Other                   | 24 (14.8)         | 8 (16.7)        |         |
| Region*                 |                   |                 | .12     |
| Northeast               | 54 (33.3)         | 10 (20.8)       |         |
| Southeast               | 40 (24.7)         | 17 (35.4)       |         |
| Midwest                 | 36 (22.2)         | 15 (31.3)       |         |
| West                    | 32 (19.8)         | 6 (12.5)        |         |
| Private insurance       | 100 (61.7)        | 33 (68.8)       | .38     |
| Heart failure etiology  |                   |                 | .34     |
| Nonischemic             | 110 (67.9)        | 29 (60.4)       |         |
| Ischemic                | 52 (32.1)         | 18 (39.6)       |         |
| Medical history         |                   |                 |         |
| Diabetes                | 31 (19.3)         | 11 (22.9)       | .58     |
| CVA                     | 10 (6.3)          | 4 (8.3)         | .62     |
| ICD                     | 53 (32.7)         | 16 (33.3)       | .94     |
| Smoking                 | 34 (21.0)         | 17 (35.4)       | .04     |
| Previous cardiac surgery| 37 (22.8)         | 12 (25.0)       | .76     |
| Inotrope-dependent      | 89 (54.9)         | 24 (50.0)       | .55     |
| Ventilator-dependent    | 55 (34.0)         | 13 (27.1)       | .37     |
| Creatinine ≥1.5 mg/dL   | 33 (20.4)         | 16 (33.3)       | .06     |
| Concurrent MCS          |                   |                 |         |
| IABP                    | 31 (19.1)         | 3 (6.3)         | .03     |
| Microaxial LVAD         | 25 (15.4)         | 5 (10.4)        | .44     |
| Durable LVAD            | 1 (0.6)           | 0               | 1.00    |

Variables are presented as percent. Statistical significant P-values were shown in bold. BMI, Body mass index; CVA, cerebrovascular accident; ICD, implantable cardioverter-defibrillator; MCS, mechanical circulatory support; IABP, intra-aortic balloon pump; LVAD, left ventricular assist device. *Northeast: UNOS regions 1, 2, and 9; Southeast: UNOS regions 3, 4, and 11; Midwest: UNOS regions 7, 8, and 10; and West: UNOS regions 5 and 6.
## TABLE E2. Risk factors for prolonged waitlist time (>8 days), status 1 only

|                        | Univariable |          |        | Multivariable |          |        |
|------------------------|-------------|----------|--------|---------------|----------|--------|
|                        | OR (95% CI) | P value  |        | OR (95% CI)   | P value  |        |
| Age, y                 | 0.98 (0.96-1.01) | .16      |        | 0.98 (0.95-0.999) | .049     |        |
| Female sex             | 1.34 (0.67-2.68) | .41      |        | 1.51 (0.71-3.22) | .28      |        |
| Obese                  | 2.02 (1.05-3.89) | .04      |        | 2.04 (1.00-4.17) | .049     |        |
| Blood type O           | 2.24 (1.17-4.32) | .02      |        | 2.42 (1.19-4.90) | .01      |        |
| White ethnicity        | 0.77 (0.39-1.54) | .46      |        |                |          |        |
| Region*                |             |          |        | Referent       | Referent |        |
| Northeast              | Referent    | –        |        | Referent       | –        |        |
| Southeast              | 2.29 (0.95-5.54) | .07      |        | 2.24 (0.87-5.75) | .09      |        |
| Midwest                | 2.25 (0.91-5.56) | .08      |        | 2.01 (0.76-5.30) | .16      |        |
| West                   | 1.01 (0.34-3.05) | .98      |        | 0.98 (0.31-3.13) | .98      |        |
| Private insurance      | 1.36 (0.69-2.71) | .38      |        |                |          |        |
| Ischemic HF etiology   | 1.39 (0.71-2.70) | .34      |        |                |          |        |
| Medical history        |             |          |        |                |          |        |
| Diabetes               | 1.25 (0.57-2.72) | .58      |        |                |          |        |
| CVA                    | 1.35 (0.41-4.53) | .62      |        |                |          |        |
| ICD                    | 1.03 (0.52-2.04) | .94      |        |                |          |        |
| Smoking                | 2.06 (1.02-4.17) | .04      |        |                |          |        |
| Previous cardiac surgery | 1.13 (0.53-2.38) | .76      |        |                |          |        |
| Inotrope-dependent     | 0.82 (0.43-1.56) | .55      |        |                |          |        |
| Ventilator-dependent   | 0.72 (0.35-1.48) | .37      |        |                |          |        |
| Creatinine ≥1.5 mg/dL  | 1.95 (0.96-3.98) | .07      |        |                |          |        |
| Concurrent MCS         |             |          |        |                |          |        |
| IABP                   | 0.28 (0.08-0.97) | .04      |        | 0.37 (0.10-1.32) | .13      |        |
| Microaxial LVAD        | 0.65 (0.24-1.81) | .41      |        |                |          |        |
| Durable LVAD           | –           | –        |        |                |          |        |

Statistical significant P-values were shown in bold. OR, Odds ratio; CI, confidence intervals; HF, heart failure; CVA, cerebrovascular accident; ICD, implantable cardioverter-defibrillator; MCS, mechanical circulatory support; IABP, intra-aortic balloon pump; LVAD, left ventricular assist device. *Northeast: UNOS regions 1, 2, and 9; Southeast: UNOS regions 3, 4, and 11; Midwest: UNOS regions 7, 8, and 10; and West: UNOS regions 5 and 6.
TABLE E3. Relationship between waitlist ≥8 days and postlisting death or deterioration, landmarked at 8 days, status 1 only

|                         | **Univariable** | **Multivariable** |
|-------------------------|-----------------|------------------|
|                         | **HR (95% CI)** | **P value**      | **HR (95% CI)** | **P value** |
| Waitlist ≥8 d           | 5.48 (2.46-12.2) | <.01             | 5.49 (2.39-12.6) | <.01        |
| Age, y                  | 1.03 (0.99-1.06) | .07              | 1.04 (1.01-1.07) | .02         |
| Female sex              | 1.15 (0.50-2.66) | .75              |                |             |
| Obese                   | 3.34 (1.48-7.57) | <.01             | 2.41 (1.05-5.52) | .04         |
| Blood type O            | 2.19 (0.99-4.88) | .054             |                |             |
| White ethnicity         | 0.50 (0.22-1.10) | .09              |                |             |
| Region*                 |                 |                  |                |             |
| Northeast               | Referent        |                  |                |             |
| Southeast               | 3.68 (1.17-11.6) | .03              |                |             |
| Midwest                 | 1.95 (0.55-6.93) | .30              |                |             |
| West                    | 1.79 (0.45-7.15) | .41              |                |             |
| Private insurance       | 0.67 (0.30-1.47) | .32              |                |             |
| Ischemic HF etiology    | 1.71 (0.78-3.77) | .18              |                |             |
| Medical history         |                 |                  |                |             |
| Diabetes                | 2.31 (0.998-5.36) | .051             |                |             |
| CVA                     | 3.34 (1.14-9.77) | .03              |                |             |
| ICD                     | 1.37 (0.62-3.06) | .44              |                |             |
| Smoking                 | 2.15 (0.97-4.80) | .06              |                |             |
| Previous cardiac surgery| 1.89 (0.84-4.28) | .14              |                |             |
| Inotrope-dependent      | 0.69 (0.32-1.53) | .37              |                |             |
| Ventilator-dependent    | 1.28 (0.56-2.89) | .56              | 1.44 (0.63-3.27) | .39         |
| Creatinine ≥1.5 mg/dL   | 2.47 (1.11-5.50) | .03              | 1.69 (0.75-3.81) | .21         |
| Concurrent MCS          |                 |                  |                |             |
| IABP                    | 0.44 (0.10-1.87) | .27              |                |             |
| Microaxial LVAD         | 1.72 (0.65-4.59) | .28              |                |             |
| Durable LVAD            |                 |                  |                |             |

Statistical significant P-values were shown in bold. HR, Hazard ratio; CI, confidence intervals; HF, heart failure; CVA, cerebrovascular accident; ICD, implantable cardioverter-defibrillator; MCS, mechanical circulatory support; IABP, intra-aortic balloon pump; LVAD, left ventricular assist device. *Northeast: UNOS regions 1, 2, and 9; Southeast: UNOS regions 3, 4, and 11; Midwest: UNOS regions 7, 8, and 10; and West: UNOS regions 5 and 6.
### TABLE E4. Characteristics of HTx recipients and donors, and operative characteristics stratified according to waitlist time

|                                                                 | ≤7 Days (n = 162) | ≥8 Days (n = 41) | P value |
|-----------------------------------------------------------------|-------------------|-----------------|---------|
| **Recipient**                                                   |                   |                 |         |
| Age, y                                                          | 53 (38-60)        | 44 (31-57)      | .04     |
| Female sex                                                      | 44 (27.2)         | 10 (24.4)       | .72     |
| BMI                                                             | 27.3 (24.2-31.0)  | 27.3 (22.3-31.3) | .56 |
| Blood type O                                                    | 57 (35.2)         | 22 (53.7)       | .03     |
| Ethnicity                                                       |                   |                 | .17     |
| White                                                           | 119 (73.5)        | 24 (58.5)       |         |
| Black                                                           | 21 (13.0)         | 8 (19.5)        |         |
| Other                                                           | 22 (13.6)         | 9 (22.0)        |         |
| **Medical history**                                            |                   |                 |         |
| Diabetes                                                        | 27 (16.7)         | 7 (17.1)        | .96     |
| Smoking                                                         | 36 (22.2)         | 12 (29.3)       | .34     |
| CVA                                                             | 10 (6.3)          | 1 (2.4)         | .47     |
| Region                                                          |                   |                 | .12     |
| Northeast                                                       | 54 (33.3)         | 10 (24.4)       |         |
| Southeast                                                      | 39 (24.1)         | 16 (39.0)       |         |
| Midwest                                                        | 36 (22.2)         | 11 (26.8)       |         |
| West                                                           | 33 (20.4)         | 4 (9.8)         |         |
| Private insurance                                              | 102 (63.0)        | 25 (61.0)       | .81     |
| **Ischemic HF etiology**                                       | 48 (29.6)         | 8 (19.5)        | .20     |
| **MCS at time of HTx**                                         |                   |                 |         |
| IABP                                                            | 32 (19.8)         | 6 (14.6)        | .45     |
| ECMO                                                            | 155 (95.7)        | 26 (63.4)       | <.01    |
| Durable LVAD                                                    | 1 (0.6)           | 5 (12.2)        | <.01    |
| Microaxial LVAD                                                 | 24 (14.8)         | 6 (14.6)        | .98     |
| Creatinine ≥1.5 mg/dL                                          | 35 (21.6)         | 10 (24.4)       | .70     |
| Inotrope-dependent                                              | 85 (52.5)         | 21 (51.2)       | .89     |
| Ventilator-dependent                                           | 47 (29.0)         | 3 (7.3)         | <.01    |
| **HTx status**                                                 |                   |                 | <.01    |
| 1                                                               | 159 (98.2)        | 32 (78.1)       |         |
| 2                                                               | 3 (1.9)           | 6 (14.6)        |         |
| 3                                                               | 0                 | 3 (7.3)         |         |
| 4                                                               | 0                 | 0               |         |
| 6                                                               | 0                 | 0               |         |
| **Donor**                                                      |                   |                 |         |
| Age, y                                                         | 32 (25-39)        | 29 (21-38)      | .12     |
| Female sex                                                     | 29 (17.9)         | 9 (22.0)        | .55     |
| Blood type O                                                   | 112 (69.1)        | 27 (65.9)       | .69     |
| BMI                                                            | 26.6 (23.5-31.2)  | 26.8 (24.6-32.2) | .56 |
| Ethnicity                                                      |                   |                 | .85     |
| White                                                          | 107 (66.1)        | 29 (70.7)       |         |
| Black                                                          | 27 (16.7)         | 6 (14.6)        |         |
| Other                                                          | 28 (17.3)         | 6 (14.6)        |         |
| **Medical history**                                            |                   |                 |         |
| Smoking                                                        | 18 (11.3)         | 1 (2.4)         | .09     |
| Hypertension                                                   | 21 (13.0)         | 7 (17.1)        | .51     |
| Cocaine use                                                    | 45 (28.0)         | 9 (23.1)        | .54     |
| Alcohol use                                                    | 32 (20.0)         | 13 (32.5)       | .09     |
| HCV-positive                                                   | 14 (8.6)          | 2 (2.4)         | .18     |
| CMV-positive                                                   | 85 (52.5)         | 22 (53.7)       | .89     |
| Trauma COD                                                     | 73 (45.1)         | 21 (51.2)       | .48     |
| Creatinine ≥1.5 mg/dL                                          | 49 (30.3)         | 17 (41.5)       | .17     |

(Continued)
### TABLE E5. Characteristics of HTx recipients and donors, and operative characteristics stratified according to waitlist time, status 1 listing only

| Recipient | ≤7 d (n = 152) | ≥8 d (n = 27) | P value |
|-----------|---------------|--------------|---------|
| Age, y    | 53 (38-60)    | 39 (28-56)   | .04     |
| Female sex| 43 (28.3)     | 8 (29.6)     | .89     |
| BMI       | 27.3 (24.2-30.7) | 28.0 (20.5-31.3) | .74     |
| Blood type O | 55 (36.2) | 14 (51.9) | .12     |
| Ethnicity | White 114 (75.0) | 17 (63.0) | .41     |
|           | Black 17 (11.2) | 5 (18.5) |         |
|           | Other 21 (13.8) | 5 (18.5) |         |
| Medical history | Diabetes 25 (16.6) | 5 (18.5) | .80     |
|          | Smoking 32 (21.1) | 8 (29.6) | .32     |
|          | CVA 9 (6.0)    | 1 (3.7)     | .63     |
| Region   | Northeast 52 (34.2) | 8 (29.6) | .14     |
|          | Southeast 34 (22.4) | 6 (22.2) |         |
|          | Midwest 34 (22.4) | 11 (40.7) |         |
|          | West 32 (21.1)  | 2 (7.4)     |         |
|          | Private insurance 96 (63.2) | 21 (77.8) | .14 |
| Ischemic HF etiology | 46 (30.3) | 7 (25.9) | .65     |
| MCS at time of HTx | IABP 31 (20.4) | 5 (18.5) | .82 |
|          | ECMO 147 (96.7) | 19 (70.4) | <.01    |
|          | Durable LVAD 0 | 2 (7.4)     | .02     |
|          | Microaxial LVAD 22 (14.5) | 2 (7.4) | .32     |
| Creatinine ≥1.5 mg/dL | 30 (19.7) | 7 (25.9) | .46     |
| Inotrope-dependent | 80 (52.6) | 15 (55.6) | .78     |
| Ventilator-dependent | 45 (29.6) | 2 (7.4) | .02     |
| HTx status | 1 152 (100) | 24 (88.9) | <.01 |
|          | 2 0          | 2 (7.1)     |         |
|          | 3 0          | 1 (3.7)     |         |
|          | 4 0          | 0           |         |
|          | 6 0          | 0           |         |

| Donor | Age, y | 32 (26-38) | 31 (19-38) | .25 |
|       | Female sex | 28 (18.4) | 9 (33.3) | .08 |
|       | Blood type O | 108 (71.1) | 18 (66.7) | .65 |
|       | BMI | 26.7 (23.5-31.3) | 28.2 (23.8-34.6) | .62 |
| Ethnicity | White 100 (65.8) | 18 (66.7) | .92 |
|         | Black 25 (16.5) | 5 (18.5) |         |
|         | Other 27 (17.8) | 4 (14.8) |         |
| Medical history | Smoking 18 (12.0) | 1 (3.7) | .20 |
|          | Hypertension 19 (12.6) | 6 (22.2) | .18 |
|          | Cocaine use 43 (28.5) | 6 (24.0) | .64 |
|          | Alcohol use 30 (20.0) | 7 (25.9) | .49 |
|          | HCV-positive 14 (9.2) | 1 (3.7) | .34 |
|          | CMV-positive 79 (52.0) | 15 (55.6) | .73 |
|          | Trauma COD 65 (42.8) | 16 (59.3) | .11 |
| Creatinine ≥1.5 mg/dL | 47 (30.9) | 11 (40.7) | .32 |

### TABLE E5. Continued

| | ≤7 d (n = 152) | ≥8 d (n = 27) | P value |
|---|---------------|--------------|---------|
| LVEF, % | 60 (57-65) | 60 (60-65) | .92 |
| Operative characteristics | Ischemic time ≥4 h | 32 (21.1) | 5 (18.5) | .76 |
|          | Distance, nautical miles | 251 (95-412) | 302 (138-447) | .24 |

Continuous variables are presented as median (interquartile range) and categorical variables are presented as n (%). Statistical significant P-values were shown in bold. BMI, Body mass index; CVA, cerebrovascular accident; HF, heart failure; MCS, mechanical circulatory support; HTx, heart transplant; IABP, intra-aortic balloon pump; ECMO, extracorporeal membrane oxygenation; LVAD, left ventricular assist device; HCV, hepatitis C virus; CMV, cytomegalovirus; COD, cause of death; LVEF, left ventricular ejection fraction.
TABLE E6. Demographic characteristics of candidates waitlisted ≥8 days stratified according to waitlist outcome

|                          | HTx (n = 41) | Death/deterioration (n = 21) | P value |
|--------------------------|-------------|-------------------------------|---------|
| Age, y                   | 44 (31-57)  | 58 (49-64)                    | <.01    |
| Female sex               | 10 (24.4)   | 8 (38.1)                      | .26     |
| BMI                      | 27.2 (22.9-32.8) | 28.6 (25.8-32.3)          | .34     |
| Blood type O             | 22 (53.7)   | 14 (66.7)                     | .33     |
| Ethnicity                |             |                               | .88     |
| White                    | 24 (58.5)   | 13 (61.9)                     |         |
| Black                    | 8 (19.5)    | 3 (14.3)                      |         |
| Other                    | 9 (22.0)    | 5 (23.8)                      |         |
| Region*                  |             |                               | .38     |
| Northeast                | 10 (24.3)   | 4 (19.1)                      |         |
| Southeast                | 16 (39.0)   | 9 (42.9)                      |         |
| Midwest                  | 11 (26.8)   | 3 (14.3)                      |         |
| West                     | 4 (9.8)     | 5 (23.8)                      |         |
| Private insurance        | 26 (63.4)   | 10 (47.6)                     | .23     |
| Heart failure etiology   |             |                               | <.01    |
| Nonischemic              | 33 (80.5)   | 9 (42.9)                      |         |
| Ischemic                 | 8 (19.5)    | 12 (57.1)                     |         |
| Diabetes                 | 7 (17.1)    | 10 (47.6)                     | .01     |
| CVA                      | 1 (2.4)     | 5 (23.8)                      | .01     |
| ICD                      | 16 (39.0)   | 8 (38.1)                      | .94     |
| Smoking                  | 12 (29.3)   | 8 (38.1)                      | .48     |
| Previous cardiac surgery | 9 (22.0)    | 7 (33.3)                      | .33     |
| Inotrope-dependent       | 21 (51.2)   | 12 (57.1)                     | .66     |
| Ventilator-dependent     | 9 (22.0)    | 6 (28.6)                      | .57     |
| Creatinine ≥1.5 mg/dL    | 14 (34.2)   | 9 (42.9)                      | .50     |
| Concurrent MCS           |             |                               |         |
| IABP                     | 3 (7.3)     | 2 (9.5)                       | .76     |
| Microaxial LVAD          | 3 (7.3)     | 4 (19.1)                      | .17     |
| Durable LVAD             | 3 (7.3)     | 0                              | .20     |
| Listing status           |             |                               | .97     |
| 1                        | 27 (65.9)   | 14 (66.7)                     |         |
| 2                        | 3 (7.3)     | 2 (9.5)                       |         |
| 3                        | 3 (7.3)     | 1 (4.8)                       |         |
| 4                        | 2 (4.8)     | 2 (9.5)                       |         |
| 6                        | 3 (7.3)     | 1 (4.8)                       |         |
| 7                        | 3 (7.3)     | 1 (4.8)                       |         |

Statistical significant P-values were shown in bold. HTx, Heart transplant; BMI, body mass index; CVA, cerebrovascular accident; ICD, implantable cardioverter-defibrillator; MCS, mechanical circulatory support; IABP, intra-aortic balloon pump; LVAD, left ventricular assist device. *Northeast: UNOS regions 1, 2, and 9; Southeast: UNOS regions 3, 4, and 11; Midwest: UNOS regions 7, 8, and 10; and West: UNOS regions 5 and 6.
TABLE E7. Demographic characteristics of candidates waitlisted ≥8 days stratified according to waitlist outcome, status 1 only

|                      | HTx (n = 27) | Death/deterioration (n = 14) | \( P \)  value |
|----------------------|-------------|----------------------------|---------------|
| Age, y               | 39 (28-56)  | 54 (39-63)                 | .18           |
| Female sex           | 8 (29.6)    | 5 (35.7)                   | .69           |
| BMI                  | 28.0 (21.1-32.8) | 30 (26.7-33.5)   | .15           |
| Blood type O         | 14 (51.9)   | 9 (64.3)                   | .45           |
| Ethnicity            |             |                            | .93           |
| White                | 17 (63.0)   | 9 (64.3)                   | .93           |
| Black                | 5 (18.5)    | 2 (14.3)                   | .15           |
| Other                | 5 (18.5)    | 3 (21.4)                   | .15           |
| Region*              |             |                            | .03           |
| Northeast            | 8 (29.6)    | 2 (14.3)                   | .15           |
| Southeast            | 6 (22.2)    | 8 (57.1)                   | .15           |
| Midwest              | 11 (40.7)   | 1 (7.1)                    | .15           |
| West                 | 2 (7.4)     | 3 (21.4)                   | .15           |
| Private insurance    | 21 (77.8)   | 8 (57.1)                   | .17           |
| Heart failure etiology |            |                            |               |
| Nonischemic          | 20 (74.1)   | 6 (42.9)                   | .049          |
| Ischemic             | 7 (25.9)    | 8 (57.1)                   |               |
| Medical history      |             |                            |               |
| Diabetes             | 5 (18.5)    | 6 (42.9)                   | .10           |
| CVA                  | 1 (3.7)     | 3 (21.4)                   | .07           |
| ICD                  | 10 (37.0)   | 5 (35.7)                   | .93           |
| Smoking              | 8 (29.6)    | 5 (35.7)                   | .69           |
| Previous cardiac surgery | 5 (18.5)   | 5 (35.7)                   | .22           |
| Inotrope-dependent   | 14 (51.9)   | 8 (57.1)                   | .75           |
| Ventilator-dependent | 6 (22.2)    | 5 (35.7)                   | .36           |
| Creatinine ≥1.5 mg/dL| 8 (29.6)    | 6 (42.9)                   | .40           |
| Concurrent MCS       |             |                            |               |
| IABP                 | 2 (7.4)     | 1 (7.1)                    | .98           |
| Microaxial LVAD      | 2 (7.4)     | 3 (21.4)                   | .19           |
| Durable LVAD         | 0           | 0                           | –             |

Statistical significant \( P \)-values were shown in bold. HTx, Heart transplant; BMI, body mass index; CVA, cerebrovascular accident; ICD, implantable cardioverter-defibrillator; MCS, mechanical circulatory support; IABP, intra-aortic balloon pump; LVAD, left ventricular assist device. *Northeast: UNOS regions 1, 2, and 9; Southeast: UNOS regions 3, 4, and 11; Midwest: UNOS regions 7, 8, and 10; and West: UNOS regions 5 and 6.