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J Heart Lung Transplant. Author manuscript; available in PMC 2023 October 23.

Published in final edited form as:

J Heart Lung Transplant. 2023 June ; 42(6): 795–806. doi:10.1016/j.healun.2023.01.004.

Clinical trends, risk factors, and temporal effects of post-transplant dialysis on outcomes following orthotopic heart transplantation in the 2018 United States heart allocation system

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Abstract

BACKGROUND: This study evaluated the current clinical trends, risk factors, and temporal effects of post-transplant dialysis on outcomes following orthotopic heart transplantation after the 2018 United States adult heart allocation policy change.

METHODS: The United Network for Organ Sharing (UNOS) registry was queried to analyze adult orthotopic heart transplant recipients after the October 18, 2018 heart allocation policy change. The cohort was stratified according to the need for post-transplant de novo dialysis. The primary outcome was survival. Propensity score-matching was performed to compare the outcomes between 2 similar cohorts with and without post-transplant de novo dialysis. The

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Disclosure statement

Dr. Kaczorowski received consultant and speaking fees for Medtronic and Abiomed. There are no direct conflicts of interest as it relates to this manuscript.

Disclaimer

The data reported here have been supplied by the United Network for Organ Sharing as the contractor for the Organ Procurement and Transplantation Network. The interpretation and reporting of these data are the responsibility of the author(s) and in no way should be seen as an official policy of or interpretation by the OPTN or the U.S. Government.

Supplementary materials

Supplementary material associated with this article can be found in the online version at https://doi.org/10.1016/j.healun.2023.01.004.

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impact of post-transplant dialysis chronicity was evaluated. Multivariable logistic regression was performed to identify risk factors for post-transplant dialysis.

RESULTS: A total of 7,223 patients were included in this study. Out of these, 968 patients (13.4%) developed post-transplant renal failure requiring de novo dialysis. Both 1-year (73.2% vs 94.8%) and 2-year (66.3% vs 90.6%) survival rates were lower in the dialysis cohort ($p < 0.001$), and the lower survival rates persisted in a propensity-matched comparison. Recipients requiring only temporary post-transplant dialysis had significantly improved 1-year (92.5% vs 71.6%) and 2-year (86.6 % vs 52.2%) survival rates compared to the chronic post-transplant dialysis group ($p < 0.001$). Multivariable analysis demonstrated low pretransplant estimated glomerular filtration (eGFR) and bridge with extracorporeal membrane oxygenation (ECMO) were strong predictors of post-transplant dialysis.

CONCLUSIONS: This study demonstrates that post-transplant dialysis is associated with significantly increased morbidity and mortality in the new allocation system. Post-transplant survival is affected by the chronicity of post-transplant dialysis. Low pretransplant eGFR and ECMO are strong risk factors for post-transplant dialysis.

Keywords

orthotopic heart; transplantation; renal failure; dialysis; adverse events; survival

Heart failure (HF) is a major public health concern with the prevalence nearing 3% in the United States.[1] Orthotopic heart transplantation (OHT) continues to be the gold standard treatment for end-stage HF after medical therapy failure.[2,3] The number of OHTs performed annually has steadily increased with more than 3,800 cases in 2021.[4] A new 6-tier heart allocation system was introduced on October 18, 2018 through the United Network for Organ Sharing (UNOS).[2,5] The new allocation system was designed to address the limitations of the prior 3-tier allocation system by improving candidate risk stratification. Such efforts are focused on improving the need-based prioritization and more equitable geographic access to donor organs. There has been a nationwide trend of increasing transplantations performed on patients with higher-risk features following the recent allocation policy change, including those who are bridged to transplantation with temporary mechanical circulatory support (MCS) devices over conventional durable left ventricular assist therapy.[6]

Recent studies have demonstrated a positive impact of the new system on waitlist times and waitlist mortality with comparable survival rates to the prior systems.[7-10] However, post-transplant complications continue to be problematic, including post-transplant renal disease.[2,3] Renal insufficiency is relatively common in end-stage HF and can be exacerbated in the setting of heart transplantation operation and immunosuppression, and it is associated with increased morbidity and mortality following heart transplantation.[11-13] Previously reported rates of renal failure requiring dialysis following heart transplantation vary widely, ranging from 4% to 28%.[12-15] There is a paucity of literature evaluating the clinical trend and impact of post-transplant dialysis on outcomes under the new allocation system. In this study, we aimed to evaluate the incidence, predictors, and temporal effects of post-transplant dialysis on outcomes following OHT under the new allocation system.

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Materials and methods

Data source

The UNOS database was utilized for this study. This is a prospectively collected registry of all solid organ transplantations performed in the United States. Patient and medical center identifiers were excluded from the analysis. This study was approved by the institutional review board at the University of Pittsburgh, and the need for informed consent for the study was waived.

Study population

This study included all adult patients (age ≥18 years) who underwent isolated OHT between October 18, 2018 and June 30, 2021 after the 2018 heart allocation policy change. Follow-up for these recipients was extended to June 30, 2022. Multivisceral transplant, heterotopic heart transplant, and/or redo OHT recipients were excluded. Additionally, patients that underwent dialysis prior to transplantation were excluded. Patients were stratified into 2 cohorts based on whether post-transplant renal failure requiring de novo dialysis occurred during the index hospitalization.

Baseline characteristics and outcomes

Recipient, donor, and transplant characteristics and outcomes data were collected from the UNOS database and were compared between the 2 groups. These demographics included age, gender, race, body mass index (BMI), HF etiology, transplant-related variables, comorbidities, most recent preoperative laboratory values, preoperative interventions, and immunosuppressants. The incidence of post-transplant dialysis in the new system (November 1, 2018-June 30, 2021) was compared to a seasonally matched, equal-length time period prior to the allocation system change (November 1, 2015-June 30, 2018). Seasonally matching was defined as time periods corresponding to the same months of the year.

The primary outcome was survival at 1 and 2 years following OHT. The secondary outcomes included postoperative complications, permanent pacemaker, hospital length of stay, rates of acute rejection requiring medical therapy, hospitalization for infection after discharge, functional status at last follow-up, and graft survival. Furthermore, a propensity score-matched comparison was made between the 2 cohorts of patients with similar baseline characteristics.

Subanalyses were performed to assess the temporal effects of dialysis on survival by further stratifying the post-transplant dialysis cohort into temporary and chronic dialysis groups. Chronic dialysis was defined as patients who developed a nonrecoverable, end-stage renal disease (ESRD) and are expected to remain on dialysis. A 90-day conditional survival analysis was also performed given the immortal time bias in the temporary dialysis group. Lastly, the impact of dialysis timing was evaluated by comparing 1- and 2-year survival between recipients who underwent pretransplant dialysis vs those who underwent de novo post-transplant dialysis.

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Data analysis

Baseline characteristics, including demographic and clinical data, are presented as frequency (percentage) for categorical variables and mean (±standard deviation) or median (interquartile range) for continuous variables. Pearson's chi-square test or Fisher's exact test were utilized for categorical comparisons. Either Student's *t*-test or analysis of variance was employed for parametric continuous variables, and Wilcoxon rank-sum test was utilized for nonparametric data. Kaplan-Meier analysis was utilized to compare overall survival between the groups.

Propensity score-matching was performed to match 2 groups of patients with similar baseline recipient, donor, and transplant characteristics. Matching was done on a 1:1 basis using nearest neighbor matching without replacement and caliper setting of 0.2 of the standard deviation of the logit propensity score. A standardized mean difference of <15% was considered adequately matched, and a standardized mean difference <10% was considered well-matched.

Multivariable logistic regression was performed to identify risk-adjusted predictors for post-transplant dialysis among transplant recipients in this study. Additionally, a separate multivariable model was constructed to identify predictors of chronic dialysis needs among those requiring dialysis in the acute post-transplant period. In these models, potential covariates were selected by performing univariable logistic regression on all baseline recipient, donor, and transplant-related variables, and all variables with significant associations ($p < 0.05$) with post-transplant dialysis were selected. Stepwise, backwards selection of potential covariables with a threshold of $p < 0.2$ was then implemented to build the final model. The multivariable models were tested for significant interactions, as well as multicollinearity. Patients with missing data were removed from multivariable modeling. The statistical analyses were performed using Stata (StataCorp LP, College Station, TX) version 16 statistical software.

Results

Baseline recipient, donor, and transplant characteristics

A total of 8,801 patients underwent isolated OHT during the study period. After excluding pediatric, pretransplant dialysis, and retransplant recipients, a total of 7,223 patients were included and analyzed. Out of these, 968 patients (13.4%) required post-transplant de novo dialysis. When comparing the rate of post-transplant dialysis to a seasonally matched, equal-length time period preceding the allocation system change, there was a higher number of recipients with post-transplant renal failure requiring dialysis under the new allocation system (13.4% vs 11.0%, $p < 0.001$) (Figure S1A and B).

The recipients requiring post-transplant dialysis had a higher proportion of White race and blood type A and a lower proportion of nonischemic HF etiology. Furthermore, dialysis recipients had higher BMI, higher serum total bilirubin, lower pretransplant estimated glomerular filtration rate (eGFR), and higher mean pulmonary capillary wedge pressure. Furthermore, the patients requiring dialysis had higher rates of pretransplant infection, transfusion, mechanical ventilation (MV), extracorporeal membrane oxygenation (ECMO),

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and prior sternotomy. Recipients in the dialysis group were more likely to receive both sex- and race-matched grafts with a longer cold ischemia time (Table 1).

As for transplant immunosuppression, induction with basiliximab was most commonly used in the dialysis group whereas induction with steroid only was most commonly used in the nondialysis group. Maintenance immunosuppression therapy with tacrolimus or mycophenolate mofetil was lower in the dialysis group. However, the rate of cyclosporin utilization was higher in the dialysis group (Table 1).

Impact of post-transplant dialysis on outcomes

The recipients requiring post-transplant dialysis experienced significantly lower 1-year (73.2% vs 94.8%, $p < 0.001$) and 2-year (66.3% vs 90.6%, $p < 0.001$) survival compared to recipients without post-transplant dialysis (Figure 1). Recipients in the dialysis group had significantly higher rates of stroke, permanent pacemaker, longer hospital length of stay, and hospitalization for infection after discharge. Furthermore, recipients in the dialysis group were less likely to be functionally independent with higher rates of hospitalization and assistance requirement during the last follow-up visit. The rate of acute rejection requiring medical therapy was comparable (Table 2).

Propensity score-matched comparisons

Propensity score-matching resulted in 1,644 patients with 822 patients requiring post-transplant dialysis and 822 patients not requiring post-transplant dialysis. Both groups were well-matched with respect to baseline recipient, donor, and transplant-related characteristics, except for the rate of ABO-matched graft and initial maintenance immunosuppression regimen (Table 3). Kaplan–Meier survival estimates remained lower in the dialysis group at 1-year (74.0% vs 94.7%, $p < 0.001$) and 2-year (66.6% vs 90.5%, $p < 0.001$) (Figure 2). In an unadjusted analysis, post-transplant dialysis was associated with over 6-fold increased risk of 2-year mortality following OHT in this propensity score-matched population (hazard ratio [HR] 6.20, 95% confidence interval [CI] 5.58-6.89, $p < 0.001$).

The dialysis group experienced a higher rate of stroke and a longer hospital length of stay. Furthermore, the recipients in the dialysis group were less likely to be functionally independent with higher rates of hospitalization and assistance requirement during the last follow-up visit. The rates of acute rejection requiring medical treatment, permanent pacemaker, and hospitalization for infection after discharge were equivalent (Table 4).

Impact of temporal factors of dialysis on survival

The impact of post-transplant dialysis chronicity was evaluated by further stratifying the post-transplant dialysis cohort into whether their dialysis requirement was temporary ($n = 580$) or chronic ($n = 148$). The temporary dialysis group had significantly improved 1-year (92.5% vs 71.6%, $p < 0.001$) and 2-year (86.6 % vs 52.2%, $p < 0.001$) survival compared to the chronic dialysis group (Figure 3A). Furthermore, 1-year (92.5 vs 71.6) and 2-year (86.5% vs 51.3%) graft survival rates were also significantly higher in the temporary dialysis group. However, the temporary dialysis group still had an increased risk of 2-year

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mortality (HR 1.43, 95% CI 1.10-1.86, $p = 0.007$) and 2-year graft failure (HR 1.44, 95% CI 1.11-1.87, $p = 0.005$) compared to the nondialysis group.

In the 90-day conditional survival analysis to account for immortal time bias in the temporary dialysis group, the temporary dialysis group continued to have higher 1-year (94.3% vs 79.7%, $p < 0.001$) and 2-year (88.4 % vs 58.1%, $p < 0.001$) survival compared to the chronic dialysis group (Figure 3B). Furthermore, the temporary dialysis group continued to have an increased risk of 2-year mortality compared to the nondialysis group (HR 1.70, 95% CI 1.27-2.27, $p < 0.001$).

When assessing the impact of dialysis timing, the post-transplant dialysis cohort was further divided into pretransplant ($n = 102$) and post-transplant de novo ($n = 967$) dialysis groups. The post-transplant dialysis group had comparable 1-year (80.4% vs 75.4%) and 2-year (73.3 % vs 66.4%) survival rates to the pretransplant dialysis group ($p = 0.1068$; Figure 3C).

Predictors of post-transplant dialysis and dialysis chronicity

Multivariable logistic regression with backwards stepwise selection was performed to identify risk factors for post-transplant dialysis. In the final model, higher BMI, HF etiologies (congenital, restrictive, and valvular), previous sternotomy and/or cardiac surgery, elevated total bilirubin, low pretransplant eGFR, MV, blood transfusion on the waitlist, ECMO, and increased graft cold ischemia time were associated with an increased odds of post-transplant dialysis (Table 5A). Low pretransplant eGFR, MV, and ECMO were strong risk factors for post-transplant dialysis, where eGFR <15 mL/min/1.73 m^2 was associated with over 16-fold increased odds of post-transplant dialysis. Recipient blood type B, induction with steroids only, and maintenance immunosuppression with tacrolimus were associated with decreased odds of post-transplant dialysis (Table 5A). In this model, a total of 24% of patients were excluded due to missing data, of which 22.9% was from the induction regimen covariable. A model without this variable is displayed in Table S1, which demonstrated comparable results.

Given the detrimental impact of chronic dialysis, a separate multivariable logistic regression was performed to identify risk factors for nonrecoverable, chronic post-transplant dialysis. The predictors of chronic post-transplant dialysis were previous sternotomy and low pretransplant eGFR (Table 5B), where eGFR <15 mL/min/1.73 m^2 was associated with a 7-fold increased odds of chronic post-transplant dialysis. ABO-matched grafts were associated with decreased odds of chronic post-transplant dialysis (odds ratio 0.49, 95% CI 0.31-0.78, $p = 0.003$).

Discussion

This is the first study to evaluate the temporal effects of post-transplant dialysis on outcomes following OHT after the 2018 heart allocation policy change. Our results demonstrate that (1) there is a higher rate of post-transplant dialysis in the current allocation system compared to the prior system, (2) post-transplant dialysis is associated with increased morbidity and mortality, (3) post-transplant survival is affected by the chronicity of post-transplant dialysis,

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(4) timing of dialysis (before or after transplantation) does not influence outcomes, and (5) low pretransplant eGFR and ECMO are strong risk factors for post-transplant dialysis.

Heart transplantation is the gold-standard treatment for advanced HF patients. With improved survival, post-transplant renal disease is progressively becoming more prevalent.[13] We observed that 13.4% of recipients experienced post-transplant renal failure requiring de novo dialysis, consistent with a previously reported incidence of 4% to 28%.[14-18] Our results demonstrated that the rate of post-transplant dialysis was significantly higher in the new allocation system compared to the previous system. This finding is not surprising as the new allocation system was designed to improve the stratification of high-risk groups and prioritize candidates with high acuity, especially those bridged with ECMO or other forms of nondischargeable MCS.

In this study, our results confirmed that post-transplant dialysis is associated with higher morbidity and mortality. This is not surprising as these recipients requiring post-transplant dialysis had several well-known risk factors for worse outcomes including pretransplant infection, transfusion, MV, ECMO, and prior sternotomy. Additionally, higher rates of complications were associated with post-transplant dialysis, including stroke, longer hospitalization, and hospitalization for infection after discharge, and the recipients with post-transplant dialysis experienced increased physical frailty and decreased functional independence. As these factors are important prognostic markers, it raises a question regarding the impact of early post-transplant physical rehabilitation to mitigate the degree of physical deterioration to improve outcomes.

A plethora of literature supports the adverse impact of post-transplant chronic kidney disease and ESRD on outcomes following OHT.[19-22] Recent evidence suggests that the prognostic implication of post-transplant acute kidney injury (AKI) may differ compared to chronic kidney disease and ESRD.[23-25] However, only a few studies have evaluated the long-term effect of AKI and temporary dialysis on heart transplant recipients.[17,18] Moreover, no studies have assessed the temporal effect of dialysis in the new allocation system. In this study, our results demonstrated that the temporary dialysis group had a significantly improved survival compared to the chronic dialysis group, with survival rates nearing the nondialysis cohort. Additionally, the pre- or post-transplant timing of dialysis did not affect survival. The exact mechanism of the adverse impact of post-transplant renal failure and dialysis on outcomes is still under further investigation, but the current evidence suggests that other comorbidities associated with renal disease and the intrinsic burden associated with dialysis may play an important role.[26,27] Furthermore, uremia-related factors may also contribute to worse outcomes, including fluid overload, electrolyte derangement, oxidative stress, endothelial dysfunction, insulin resistance, and excess sympathetic tone.[28,29]

In this study, several risk factors for post-transplant dialysis have been identified to adversely impact post-transplant outcomes. These include increased BMI, elevated bilirubin, low eGFR, prior sternotomy, pretransplant blood transfusion, ECMO, MV, and increased graft cold ischemia time.[30-32] These findings are important for candidate selection and counseling when OHT is being considered. Identification and risk stratification may help mitigate

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the adverse effects of these high-risk features and improve outcomes in this vulnerable population.

In our study, low pretransplant eGFR was the strongest predictor of post-transplant dialysis. In a prior study utilizing the UNOS database, a similar conclusion was drawn where a lower pretransplant eGFR was directly proportional to the increased mortality with an adjusted hazard ratio for mortality of 1.55 (95% CI 1.41-1.70) for eGFR <30 mL/ min/ 1.73 m^2.[33] Moreover, low pretransplant eGFR was an independent predictor for ESRD and subsequent kidney transplantation.[33] This is also in accordance with our results, where low pretransplant eGFR was an independent risk factor for ESRD requiring chronic dialysis. There is growing evidence supporting improved outcomes with combined heart-kidney (CHK) transplantation compared to heart transplants alone in recipients with advanced renal disease or on dialysis.[34-37] Therefore, early consideration of CHK transplantation may be warranted in candidates with low pretransplant eGFR as these patients are at heightened risk for post-transplant dialysis and subsequent ESRD.

Bridge to transplant with ECMO was another significant risk factor with >80% increased odds of requiring post-transplant dialysis. This has a significant clinical implication as the new allocation system was designed to improve the stratification of high-risk groups and prioritize candidates with temporary MCS given their acuity.[7] Prior studies have demonstrated that there are 4-times more patients bridged with ECMO compared to the old system.[19,20] As more acutely ill patients supported with temporary MCS undergo OHT under the new allocation system, the incidence of post-transplant dialysis may become increasingly more prevalent. Therefore, additional studies are necessary to evaluate optimal renal protection methods and candidate stratification for CHK transplantation given the shift in allocation paradigm and recipient acuity and characteristics.

Study limitations

There are several limitations to this study. Foremost, the study is retrospective and nonrandomized in nature. The study only included and analyzed recipients after the allocation policy change leading to selection bias, which limits the generalizability of the findings to prior eras. Similar to other multicenter databases, the UNOS registry is prone to inaccurate data entry and missing data. Furthermore, there is limited granular information on the recipient, donor, and transplant-related characteristics. These include practice patterns, individualized postoperative management, surgeon preference, institutional preferences, bridging modality, and recipient and donor selection. Furthermore, given the limited, static nature of the available data, the dynamicity of the pretransplant renal function could not be captured. This database does differentiate between temporary and chronic dialysis needs in patient follow-up data records. However, the exact duration and other temporal factors of dialysis are not collected, which could be useful in the quantification of the impacts of dialysis duration on post-transplant outcomes. Furthermore, we acknowledge the immortal time bias in the temporary dialysis group given the period to survive dialysis support, which could have contributed to higher early survival. Lastly, given the broad spectrum of renal diseases and individualized renal replacement therapy, the inconsistency and heterogenicity of the cohort may have affected the results.

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Conclusion

This is the first study to evaluate the temporal effects of post-transplant dialysis on outcomes following OHT after the 2018 adult heart allocation policy change. The present study of 7,223 adult OHT recipients from the current allocation system demonstrates that post-transplant dialysis is associated with worse outcomes. The rate of post-transplant renal failure requiring dialysis is significantly higher in the current allocation system compared to the prior system. Survival appears to be affected by the chronicity of post-transplant dialysis requirements, where there was a significant survival improvement with temporary dialysis. Low pretransplant eGFR and ECMO are strong predictors of post-transplant dialysis.

Supplementary Material

Refer to Web version on PubMed Central for supplementary material.

Abbreviations:

AKI	acute kidney injury
BMI	body mass index
CHK	combined heart-kidney transplantation
CI	confidence interval
ECMO	extracorporeal membrane oxygenation
eGFR	estimated glomerular filtration
ESRD	end-stage renal disease
HF	heart failure
HR	hazard ratio
MCS	mechanical circulatory support
MV	mechanical ventilation
OHT	orthotopic heart transplantation
UNOS	United Network for Organ Sharing

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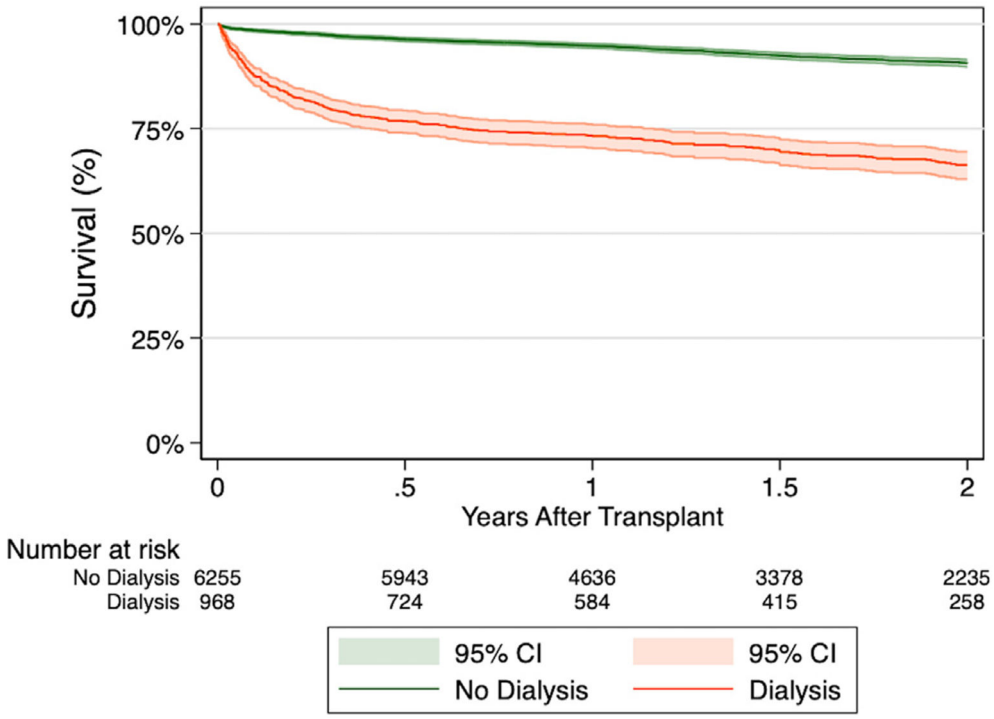

Figure 1.

Unadjusted Kaplan-Meier estimates for survival following heart transplantation stratified by post-transplant dialysis requirements in unmatched cohorts.

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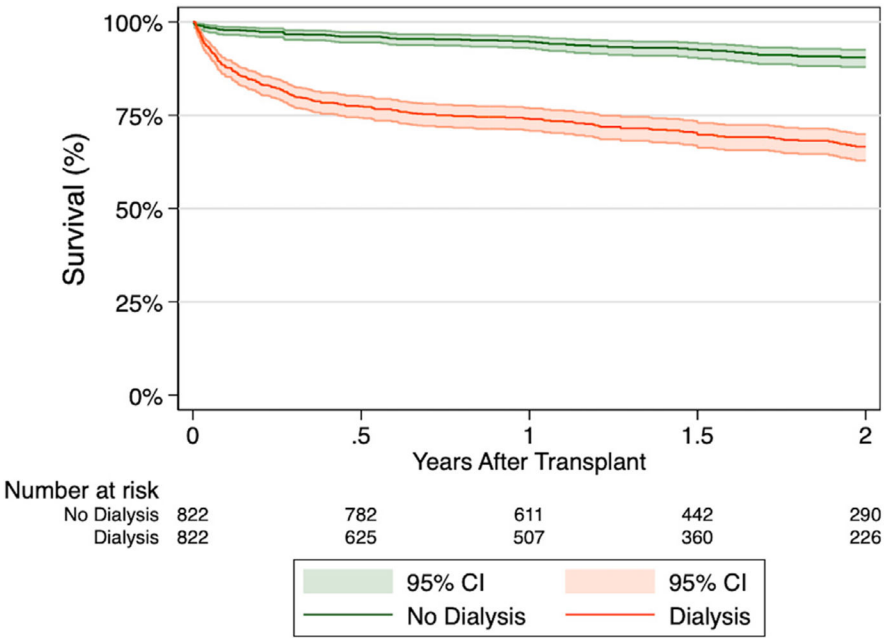

Figure 2.

Comparison of survival stratified by post-transplant dialysis in propensity score-matched cohorts.

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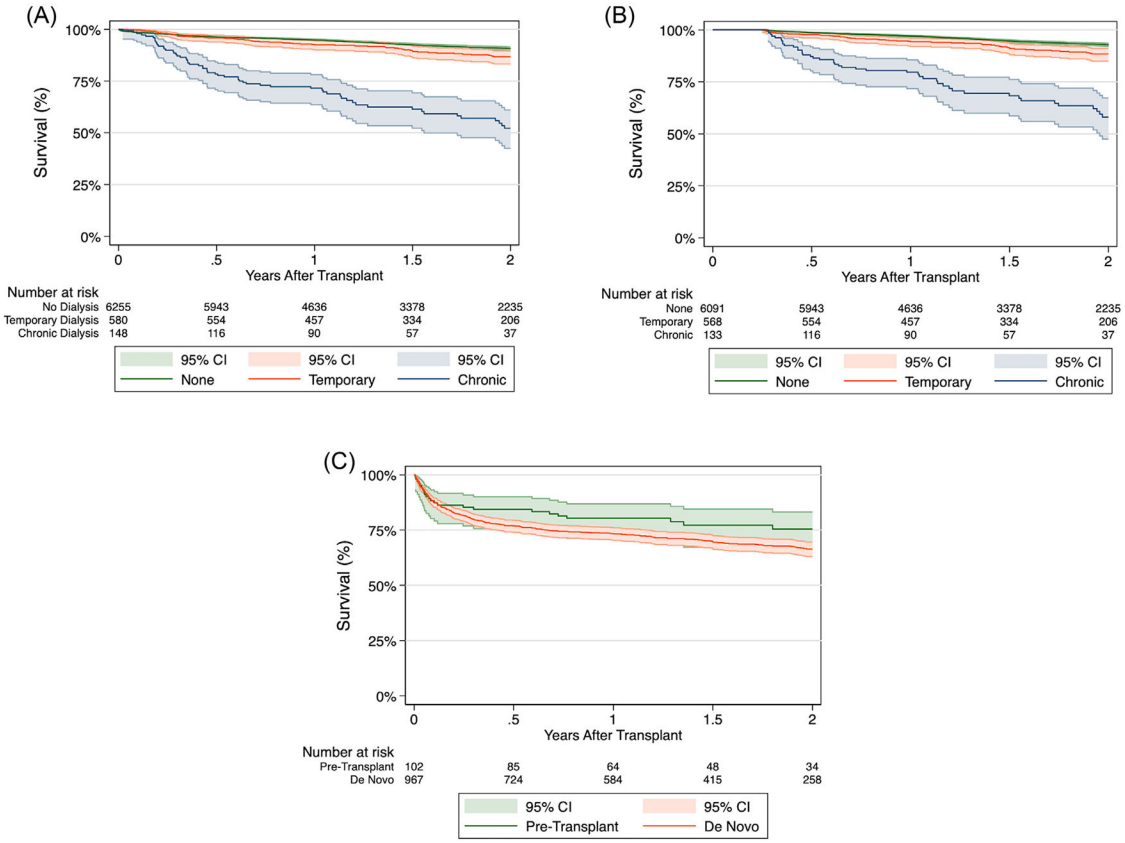

Figure 3.

Kaplan-Meier estimates for survival following heart transplantation. (A) Comparison of survival stratified by post-transplant dialysis requirements and dialysis chronicity. (B) Comparison of survival stratified by post-transplant dialysis requirements and dialysis chronicity with conditional 90-day survival. (C) Comparison of survival stratified by pretransplant dialysis and post-transplant de novo dialysis.

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Table 1

Baseline Recipient, Donor, and Transplant Characteristics Stratified by Post-Transplant Dialysis Requirement

	No dialysis (*n* = 6,255)	Post-transplant dialysis (*n* = 968)	*p*-value
Recipient characteristics			
Age (years)	57 (46-63)	57 (48-64)	0.095
Female	1,729 (27.6%)	258 (26.7%)	0.52
Race			0.003
White	3,893 (62.6%)	659 (68.4%)	
Black	1,466 (23.6%)	196 (20.3%)	
Hispanic	608 (9.8%)	75 (7.8%)	
Asian	225 (3.6%)	26 (2.7%)	
Other	28 (0.5%)	8 (0.8%)	
Missing	35 (0.6%)	4 (0.4%)	
Body mass index (kg/m^2)	27.58 ± 4.94	28.91 ± 4.84	<0.001
Recipient blood type			0.017
A	2,469 (39.5%)	403 (41.6%)	
AB	306 (4.9%)	60 (6.2%)	
B	997 (15.9%)	121 (12.5%)	
O	2,483 (39.7%)	384 (39.7%)	
Heart failure etiology			<0.001
Non-Ischemic	3,530 (56.4%)	487 (50.3%)	
Ischemic	1,760 (28.1%)	272 (28.1%)	
Congenital	204 (3.3%)	67 (6.9%)	
Restrictive	278 (4.4%)	48 (5.0%)	
Valvular	54 (0.9%)	18 (1.9%)	
Hypertrophic	8 (0.1%)	1 (0.1%)	
Other	199 (3.2%)	43 (4.4%)	
Missing	222 (3.5%)	32 (3.3%)	
Prior sternotomy and/or cardiac surgery	2,606 (41.7%)	496 (51.2%)	<0.001
Diabetes mellitus	1,668 (26.7%)	287 (29.6%)	0.053
Total bilirubin (mg/dL)	0.94 ± 1.52	1.30 ± 2.61	<0.001

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	No dialysis (*n* = 6,255)	Post-transplant dialysis (*n* = 968)	*p*-value
eGFR (mL/min/1.73 m^2)	72.32 ± 34.83	65.27 ± 78.84	<0.001
Positive CMV serology	3,390 (54.2%)	519 (53.6%)	0.74
Pretransplant infection	622 (10.0%)	122 (12.7%)	0.010
Blood transfusion while on waitlist	766 (12.3%)	172 (17.9%)	<0.001
Pretransplant mechanical ventilation	101 (1.6%)	40 (4.1%)	<0.001
Intravenous inotropes	2,433 (38.9%)	355 (36.7%)	0.19
Intra-aortic balloon pump	1,797 (28.7%)	257 (26.5%)	0.16
ECMO	265 (4.2%)	80 (8.3%)	<0.001
VAD support			0.44
None	3,983 (63.7%)	595 (61.5%)	
LVAD	2,135 (34.1%)	349 (36.1%)	
RVAD	22 (0.4%)	3 (0.3%)	
TAH	24 (0.4%)	2 (0.2%)	
LVAD + RVAD	91 (1.5%)	19 (2.0%)	
Mean pulmonary artery pressure (mm Hg)	26.91 ± 10.11	27.57 ± 10.05	0.067
Mean capillary wedge pressure (mm Hg)	17.70 ± 8.76	18.57 ± 8.64	0.006
Pulmonary vascular resistance (Woods units)	2.39 ± 4.50	2.23 ± 1.71	0.29
Trans-pulmonary gradient (mm Hg)	9.14 ± 5.63	9.02 ± 5.84	0.55
Donor characteristics			
Age (years)	32 (24-40)	32 (24-40)	0.95
Female	1,777 (28.4%)	284 (29.3%)	0.55
Race			0.90
White	3,956 (63.2%)	628 (64.9%)	
Black	1,026 (16.4%)	152 (15.7%)	
Asian	1,079 (17.3%)	159 (16.4%)	
Hispanic	101 (1.6%)	16 (1.7%)	
Other	93 (1.5%)	13 (1.3%)	
Body mass index (kg/m^2)	27.93 ± 6.25	28.22 ± 6.37	0.18
Blood type			0.16
A	2,262 (36.2%)	380 (39.3%)	
AB	64 (1.0%)	7 (0.7%)	

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	No dialysis (*n* = 6,255)	Post-transplant dialysis (*n* = 968)	*p*-value
B	707 (11.3%)	94 (9.7%)	
O	3,222 (51.5%)	487 (50.3%)	
Diabetes mellitus	230 (3.7%)	47 (4.9%)	0.077
Hypertension	2,179 (34.9%)	325 (33.6%)	0.44
Serum creatinine (mg/dL)	1.67 ± 1.77	1.65 ± 1.77	0.75
Graft LVEF <50%	82 (1.3%)	19 (2.0%)	0.11
Positive CMV serology	3,870 (62.1%)	577 (60.0%)	0.20
Hepatitis C	757 (12.1%)	98 (10.1%)	0.076
Matching and transplant characteristics			
Sex matched	4,899 (78.3%)	788 (81.4%)	0.029
Race matched	3,016 (48.2%)	525 (54.2%)	<0.001
HLA matched (≤3 loci mismatch)	819 (13.1%)	114 (11.8%)	0.26
ABO matched	5,300 (84.7%)	815 (84.2%)	0.67
CMV matched	3,296 (52.9%)	494 (51.4%)	0.36
Waitlist time (days)	34 (9-186)	35 (8-221.5)	0.97
Donor distance to transplanting center (nautical miles)	222 (84-402)	243.5 (97.5-406)	0.078
Graft cold ischemic time (hours)	3.4 (2.8-4.0)	3.5 (3.0-4.1)	<0.001
Immunosuppression			
Induction regimen			<0.001
ATGAM	94 (2.0%)	25 (3.3%)	
Thymoglobulin	1,054 (22.0%)	185 (24.5%)	
Basiliximab	1,517 (31.6%)	294 (38.9%)	
Steroids only	2,007 (41.8%)	229 (30.3%)	
Other	128 (2.7%)	23 (3.0%)	
Missing	1,455 (23.3%)	212 (21.9%)	
Components of initial maintenance regimen			
Steroids	5,724 (91.5%)	871 (90.0%)	0.12
Tacrolimus	6,012 (96.1%)	853 (88.1%)	<0.001
Mycophenolate mofetil	5,515 (88.2%)	767 (79.2%)	<0.001
Mycophenolic acid	574 (9.2%)	83 (8.6%)	0.54
Cyclosporin	40 (0.6%)	20 (2.1%)	<0.001

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Abbreviations: CMV, cytomegalovirus; ECMO, extracorporeal membrane oxygenation; eGFR, estimated glomerular filtration rate; HLA, human leukocyte antigen; LVAD, left ventricular assist device; LVEF, left ventricular ejection fraction; RVAD, right ventricular assist device; TAH, total artificial heart; VAD, ventricular assist device.

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Table 2

Post-Transplant Outcomes Stratified by Post-Transplant Dialysis Requirement

	No dialysis (*n* = 6,255)	**Post-transplant dialysis (*n* = 968)**	***p*-value**
Stroke	182 (2.9%)	87 (9.1%)	<0.001
Permanent pacemaker	104 (1.7%)	27 (2.8%)	0.014
Hospital LOS (days)	16 (11-22)	33 (21-57)	<0.001
Treated acute rejection	671 (10.7%)	118 (12.2%)	0.17
Hospitalization for infection after discharge	811 (33.5%)	160 (45.1%)	<0.001
Functional status at last follow-up			<0.001
Hospitalized	261 (5.0%)	174 (21.1%)	
Requires assistance	658 (12.7%)	178 (21.6%)	
Functionally independent	4,274 (82.3%)	471 (57.2%)	

Abbreviation: LOS, length of stay.

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Table 3

Baseline Recipient, Donor, and Transplant Characteristics Stratified by Post-Transplant Dialysis Requirement in Propensity Score-Matched Cohorts

	No dialysis (*n* = 822)	Post-transplant dialysis (*n* = 822)	SMD
Recipient characteristics			
Recipient age (years)	57 (49-64)	57 (48-64)	0.003
Female	226 (27.5%)	225 (27.4%)	0.003
Race			0.002
White	569 (69.2%)	572 (69.6%)	
Black	166 (20.2%)	164 (20.0%)	
Hispanic	65 (7.9%)	63 (7.7%)	
Asian	22 (2.7%)	19 (2.3%)	
Other	0 (0.0%)	4 (0.5%)	
Body mass index (kg/m^2)	28.81 ± 4.90	28.90 ± 4.77	0.019
Recipient blood type			0.002
A	340 (41.4%)	339 (41.2%)	
AB	38 (4.6%)	48 (5.8%)	
B	125 (15.2%)	106 (12.9%)	
O	319 (38.8%)	329 (40.0%)	
Heart failure etiology			0.001
Nonischemic	418 (50.9%)	419 (51.0%)	
Ischemic	255 (31.0%)	226 (27.5%)	
Congenital	27 (3.3%)	52 (6.3%)	
Restrictive	33 (4.0%)	43 (5.2%)	
Valvular	14 (1.7%)	13 (1.6%)	
Hypertrophic	1 (0.1%)	1 (0.1%)	
Other	35 (4.3%)	39 (4.7%)	
Diabetes mellitus	242 (29.4%)	252 (30.7%)	0.027
Total bilirubin (mg/dL)	1.07 ± 2.05	1.16 ± 2.15	0.040
eGFR (mL/min/1.73 m^2)	62.81 ± 25.62	61.31 ± 31.97	0.052
Prior sternotomy and/or cardiac surgery	437 (53.2%)	413 (50.2%)	0.058
Positive CMV serology	451 (54.9%)	436 (53.0%)	0.037

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	No dialysis (*n* = 822)	Post-transplant dialysis (*n* = 822)	SMD
Pretransplant infection	85 (10.3%)	94 (11.4%)	0.035
Blood transfusion while on waitlist	135 (16.4%)	135 (16.4%)	<0.001
Pretransplant mechanical ventilation	25 (3.0%)	21 (2.6%)	0.029
Intravenous inotropes	298 (36.3%)	293 (35.6%)	0.013
Intra-aortic balloon pump	232 (28.2%)	224 (27.3%)	0.022
ECMO	56 (6.8%)	46 (5.6%)	0.050
Ventricular assist device			0.002
None	504 (61.3%)	502 (61.1%)	
LVAD	300 (36.5%)	302 (36.7%)	
RVAD	0 (0.0%)	2 (0.2%)	
TAH	2 (0.2%)	1 (0.1%)	
LVAD + RVAD	16 (1.9%)	15 (1.8%)	
Mean pulmonary artery pressure (mm Hg)	28.04 ± 10.31	27.64 ± 10.06	0.039
Mean capillary wedge pressure (mm Hg)	18.95 ± 8.75	18.51 ± 8.58	0.051
Pulmonary vascular resistance (Woods units)	2.25 ± 1.81	2.25 ± 1.71	0.005
Trans-pulmonary gradient (mm Hg)	9.09 ± 6.15	9.13 ± 5.78	0.006
Donor characteristics			
Age (years)	32 (25-40)	32 (24-40)	0.013
Female	257 (31.3%)	244 (29.7%)	0.034
Race			0.001
White	539 (65.6%)	541 (65.8%)	
Black	129 (15.7%)	126 (15.3%)	
Asian	131 (15.9%)	131 (15.9%)	
Hispanic	10 (1.2%)	12 (1.5%)	
Other	13 (1.6%)	12 (1.5%)	
Body mass index (kg/m^2)	28.03 ± 5.73	28.21 ± 6.29	0.029
Blood type			0.012
A	320 (38.9%)	323 (39.3%)	
AB	7 (0.9%)	7 (0.9%)	
B	75 (9.1%)	80 (9.7%)	
O	420 (51.1%)	412 (50.1%)	

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	No dialysis (*n* = 822)	Post-transplant dialysis (*n* = 822)	SMD
Diabetes mellitus	47 (5.7%)	39 (4.7%)	0.044
Hypertension	286 (34.8%)	284 (34.5%)	0.005
Graft LVEF <50%	16 (1.9%)	17 (2.1%)	0.009
Positive CMV serology	495 (60.2%)	492 (59.9%)	0.007
Hepatitis C	93 (11.3%)	88 (10.7%)	0.019
Matching and transplant characteristics			
Sex matched	663 (80.7%)	673 (81.9%)	0.031
Race matched	460 (56.0%)	451 (54.9%)	0.022
HLA matched (≤3 loci mismatch)	95 (11.6%)	97 (11.8%)	0.008
ABO matched	691 (84.1%)	700 (85.2%)	0.30
CMV matched	424 (51.6%)	426 (51.8%)	0.005
Waitlist time (days)	37 (10-236)	38.5 (9-246)	0.002
Donor distance to transplanting center (nautical miles)	231.5 (97-414)	240 (98-406)	0.008
Graft cold ischemic time (hours)	3.5 (3.0-4.1)	3.5 (3.0-4.1)	0.029
Immunosuppression			
Induction regimen			<0.001
ATGAM	7 (1.1%)	23 (3.6%)	
Thymoglobulin	140 (22.4%)	144 (22.6%)	
Basiliximab	196 (31.3%)	259 (40.6%)	
Steroids only	267 (42.7%)	193 (30.3%)	
Other	16 (2.6%)	19 (3.0%)	
Missing	196 (23.8%)	184 (22.4%)	
Components of initial maintenance regimen			
Steroids	749 (91.1%)	745 (90.6%)	0.73
Tacrolimus	784 (95.4%)	723 (88.0%)	<0.001
Mycophenolate mofetil	718 (87.3%)	648 (78.8%)	<0.001
Mycophenolic acid	73 (8.9%)	75 (9.1%)	0.86
Cyclosporin	8 (1.0%)	19 (2.3%)	0.033

Abbreviations: CMV, cytomegalovirus; ECMO, Extracorporeal membrane oxygenation; eGFR, estimated glomerular filtration rate; HLA, human leukocyte antigen; LVAD, left ventricular assist device; LVEF, left ventricular ejection fraction; RVAD, right ventricular assist device; SMD, standardized mean difference; TAH, total artificial heart; VAD, ventricular assist device.

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Table 4

Post-Transplant Outcomes Stratified by Post-Transplant Dialysis Requirement in Propensity Score-Matched Cohorts

	No dialysis (*n* = 822)	**Post-transplant dialysis (*n* = 822)**	***p*-value**
Stroke	31 (3.8%)	74 (9.1%)	<0.001
Permanent pacemaker	12 (1.5%)	23 (2.8%)	0.058
Hospital LOS (days)	17 (12-24)	33 (21-56)	<0.001
Treated acute rejection	79 (9.6%)	103 (12.5%)	0.059
Hospitalization for infection after discharge	116 (37.1%)	134 (44.8%)	0.051
Functional status at last follow-up			<0.001
Hospitalized	34 (4.9%)	146 (20.7%)	
Requires assistance	98 (14.1%)	158 (22.4%)	
Functionally independent	562 (81.0%)	400 (56.8%)	

Abbreviation: LOS, length of stay.

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Table 5

Multivariable Logistic Regression Models. (A) Model for Dialysis Following Heart Transplant. (B) Model for Nonrecoverable, Chronic Dialysis Requirement Among Recipients With Post-Transplant Renal Failure Requiring Dialysis

A.			
	Odds ratio	**95% confidence interval**	***p*-value**
BMI, increasing per 1 kg/m^2	1.04	1.03, 1.06	<0.001
Recipient blood type			
A	Ref	Ref	Ref
AB	1.21	0.85, 1.73	0.292
B	0.76	0.59. 0.98	0.037
O	0.91	0.76, 1.09	0.294
Heart failure etiology			
Nonischemic	Ref	Ref	Ref
Ischemic	0.92	0.76, 1.12	0.426
Congenital	2.59	1.82, 3.68	<0.001
Restrictive	1.52	1.05. 2.20	0.026
Valvular	2.02	1.04, 3.93	0.038
Hypertrophic	1.32	0.15, 11.74	0.806
Previous sternotomy and/or cardiac surgery	1.27	1.07, 1.51	0.007
Total bilirubin, increasing, per 1 mg/dL	1.09	1.04, 1.13	<0.001
eGFR at transplant, mL/min/1.73 m^2			
≥90	Ref	Ref	Ref
60-89	1.76	1.33, 2.32	<0.001
30-59	2.82	2.15, 3.70	<0.001
15-29	4.57	2.75, 7.61	<0.001
<15	16.51	3.51, 77.65	<0.001
Mechanically ventilated at time of transplant	1.85	1.13, 3.06	0.015
Blood transfusion on waitlist	1.45	1.16, 1.80	0.001
Pretransplant ECMO	1.82	1.27, 2.60	0.001
Sex-matched donor and recipient	1.17	0.95, 1.43	0.131
Race-matched donor and recipient	1.12	0.95, 1.32	0.161

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Graft cold ischemia time, increasing, per hour	1.11	1.03, 1.19	0.007
Induction regimen			
ATGAM	Ref	Ref	Ref
Thymoglobulin	0.64	0.39, 1.05	0.077
Basiliximab	0.69	0.42, 1.12	0.132
Steroids only	0.47	0.29, 0.78	0.003
Other	0.65	0.34, 1.27	0.211
Initial tacrolimus maintenance immunosuppression	0.36	0.25, 0.47	<0.001
Initial mycophenolate mofetil maintenance immunosuppression	0.83	0.65, 1.06	0.130

1,737 (24%) of study patients were excluded from the final model due to incomplete data.

B.

	Odds ratio	**95% confidence interval**	***p*-value**
BMI, increasing per 1 kg/m^2	1.03	0.99, 1.07	0.179
Previous sternotomy and/or cardiac surgery	1.96	1.32, 2.90	0.001
eGFR at transplant, mL/min/1.73 m^2			
≥90	Ref	Ref	Ref
60-89	1.75	0.77, 3.95	0.180
30-59	1.54	0.69, 3.42	0.293
15-29	2.69	0.95, 7.63	0.063
<15	7.68	1.77, 33.28	0.006
IABP at time of transplant	0.69	0.43, 1.10	0.118
Female donor	1.48	0.99, 2.22	0.059
ABO-matched donor and recipient	0.49	0.31, 0.78	0.003
Race-matched donor and recipient	0.71	0.48, 1.03	0.071
Mycophenolic acid as initial maintenance immunosuppression	0.59	0.28, 1.26	0.173
Cyclosporin as initial maintenance immunosuppression	2.57	0.95, 6.92	0.062

Abbreviations: BMI, body mass index; ECMO, extracorporeal membrane oxygenation; eGFR, estimated glomerular filtration rate; IABP, intra-aortic balloon pump.

No study patients were excluded from the final model due to incomplete data.