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Heart transplantation graft survival following donation after circulatory death via thoracoabdominal normothermic regional perfusion

Sarah Y. Park, MD,[a,1,*] Rocio Lopez, MS, MPH,[b,c,2] Michael J. Kirsch, MD, MSCR,[a,3] Elizabeth J. Bashian, MD,[a,4] Emily Hay-Arthur, BA,[a,5] Jack Zakrzewski, MD,[a,6] Jesse D. Schold, PhD,[b,c,d,7] Nicholas R. Teman, MD,[a,8] Jordan R.H. Hoffman, MD, MPH,[a,9] and Michael T. Cain, MD[a,10]

[a]*Department of Surgery, Division of Cardiothoracic Surgery, University of Colorado Anschutz Medical Campus, Aurora, CO*
[b]*Department of Surgery, Division of Transplant Surgery, University of Colorado Anschutz Medical Campus, Aurora, CO*
[c]*Colorado Center for Transplantation Care, Research and Education (CCTCARE), Aurora, CO*
[d]*Department of Epidemiology, University of Colorado Anschutz Medical Campus, Aurora, CO*

KEYWORDS:
Heart transplantation;
Graft survival;
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Thoracoabdominal

BACKGROUND: The impact of thoracoabdominal normothermic regional perfusion (TA-NRP) use in donation after circulatory death (DCD) on rates of graft survival after heart transplantation has yet to be established.

METHODS: A cohort study of the Scientific Registry of Transplant Recipients was performed identifying all primary adult heart transplants performed in the United States between January 1, 2020, and

Abbreviations: BMI, body mass index; CAV, cardiac allograft vasculopathy; CDC, Centers for Disease Control and Prevention; CAD, coronary artery disease; DPP, direct procurement and perfusion; DBD, donation after brain death; DCD, donation after circulatory death; eGFR, estimated glomerular filtration rate; ECMO, extracorporeal membrane oxygenation; HRSA, Health Resources and Services Administration; IMPACT, Index for Mortality Prediction After Cardiac Transplantation; IABP, intra-aortic balloon pump; LVAD, left ventricular assist device; OPTN, Organ Procurement and Transplantation Network; PGD, primary graft dysfunction; SRTR, Scientific Registry of Transplant Recipients; TA-NRP, Thoracoabdominal normothermic regional perfusion; UNOS, United Network for Organ Sharing

*Corresponding author: Sarah Y. Park, MD, Mail Stop C310, 12631 East 17th Avenue, Room 6602, Aurora, CO 80045.
E-mail address: sarah.3.park@cuanschutz.edu.
[1] ORCID 0000–0003-4893–1245
[2] ORCID 0000–0002-4319–420X
[3] ORCID 0000–0003-2324–844X
[4] ORCID 0000–0002-9994–3804
[5] ORCID 0009–0003-1249–8539
[6] ORCID 0000–0002-9824–8148
[7] ORCID 0000–0002-5341–7286
[8] ORCID 0000–0001-7711–6966
[9] ORCID 0000–0003-3359–5277
[10] ORCID 0000–0003-4029–2557

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normothermic regional perfusion;
Donation after circulatory death

May 31, 2024, comparing donation after brain death (DBD), DCD with direct procurement and perfusion (DPP) (defined as declaration of circulatory death to cross clamp < 30 min), and DCD with TA-NRP (defined as declaration of circulatory death to cross clamp > 40 min). The primary outcome was graft loss (re-transplant or death).

RESULTS: There were 474 (3.5%) DCD TA-NRP, 899 (6.6%) DCD DPP, and 12,185 (89.9%) DBD heart transplants during the study period, with varying donor and baseline characteristics, including more male and non-Hispanic White DCD TA-NRP recipients, and fewer DCD TA-NRP recipients listed as Status 1. On multivariable analysis, graft survival rates did not significantly differ between cohorts [Adjusted Hazard Ratio (aHR) (95% CI): 0.98 (0.70, 1.37) for DCD TA-NRP vs. DBD; and 1.04 (0.69, 1.56) for DCD TA-NRP vs. DCD DPP].

CONCLUSION: DCD TA-NRP recovery in heart transplantation yields comparable rates of two-year graft survival compared to DCD DPP and DBD recovery, supporting greater utilization of TA-NRP recovery in DCD allografts.

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Introduction

Donation after circulatory death (DCD) remains a relatively new reinvigorated avenue to increase the donor organ pool. Recipient outcomes associated with direct procurement and perfusion (DPP) which involves *ex-situ* machine perfusion have shown promise, and the expansion of thoracoabdominal normothermic regional perfusion (TA-NRP) has provided additional pathways for DCD procurement to increase donor organ yield.[1–3] DCD TA-NRP was introduced in the United States in 2020 and has progressively gained popularity as studies have demonstrated equivocal post-heart transplant survival compared to DBD and DCD DPP, with some recent studies suggesting improved long-term survival with DCD TA-NRP recovery compared to DCD DPP recovery.[1,4–6]

The impact of TA-NRP recovery on rates of heart transplant allograft graft survival remains to be established. Li et al. suggested DCD heart transplants had higher rates of acute rejection during the index hospitalization and readmissions for rejection than DBD heart transplants, yet single-center studies and other database studies have failed to validate these findings.[6–8] As TA-NRP recovery of DCD hearts is still a relatively new method, evaluation of data regarding graft survival results has been limited to date.

We aimed to evaluate rates of graft and patient survival associated with DCD TA-NRP recovery in comparison to DCD DPP and DBD recovery.

Materials and methods

Data description

This study used data from the Scientific Registry of Transplant Recipients (SRTR). The SRTR data system includes data on all donors, wait-listed candidates, and transplant recipients in the US, submitted by the members of the Organ Procurement and Transplantation Network (OPTN). The Health Resources and Services Administration (HRSA), U.S. Department of Health and Human Services provides oversight to the activities of the OPTN and SRTR contractors. We used the March 2025 standard analysis files from the SRTR, which have a recipient cohort censoring date of June 1, 2024, in addition to the death date time, donor hospital, and deceased donor to hospital supplemental files. This study is in compliance with the International Society for Heart and Lung Transplantation ethics.

We identified adult subjects listed for primary heart transplantation between January 1, 2020, and May 31, 2024. The following exclusions were made: recipients < 18 years of age at time of listing, living donor transplant, multi-organ transplant, re-transplantation, unknown donor type (DCD vs. DBD), DCD donor missing death pronouncement time, DCD donor with indeterminate duration from death to cross clamp (31–39 min), DCD donors with outlier time from death to cross clamp (> 308 min), and relisting during the study period (Figure 1). For candidates originally listed as pediatric, the pediatric urgency status codes were retained in the registry even if the candidate had turned 18 years or older at the time of transplant. This exclusion ensures consistency in how urgency is defined across the cohort.

Variable definitions

The method of recovery is not documented in SRTR, so DCD transplants were separated by procurement duration – the time interval between declaration of death to aortic cross clamp – into DPP if < 30 min or TA-NRP if > 40 min, as previously described (Supplemental Figure 1a).[2] Agonal start time to aortic cross clamp did not demonstrate a clear transition, as previously demonstrated by Ran and colleagues (Supplemental Figure 1b).[4] The distance between the donor hospital and transplant center was calculated as the geodetic distance between the zip code centroids in nautical miles. We used the race-free 2021 CKD-EPI creatinine-

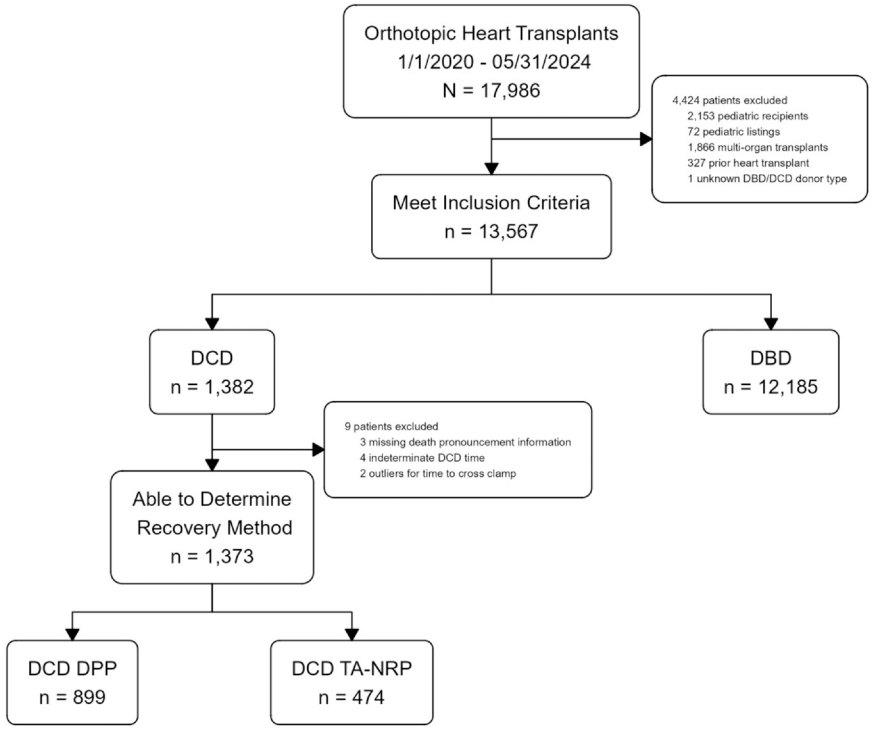

Figure 1 STROBE diagram.

based estimated glomerular filtration rate (eGFR) equation to calculate recipient and donor eGFR.[9] We also calculated the Index for Mortality Prediction After Cardiac Transplantation (IMPACT) score and predicted heart mass (PHM).[10,11]

Our primary outcome was time to graft loss. We defined graft survival time as the number of months from transplantation to heart re-transplantation or patient death, whichever occurred first. Patients were censored at the earliest of recipient censoring cohort date (June 1, 2024) or 2-year post-transplant).

Secondary outcomes included time to patient death, defined as months from transplantation until death or the earliest of the recipient censoring cohort date or 2-years. Secondary outcomes also included presence of treated acute rejection (prior to discharge or during the first-year post-transplant), hospital readmissions (any reason, for rejection, for infection), coronary artery disease (CAD), left ventricular ejection fraction (LVEF), and use of maintenance immunosuppression during the first-year post-transplant. Since transplant centers are not required to follow patients after graft loss, we restricted these analyses to the subgroup of subjects who had a completed one-year post-transplant follow-up form and had not experienced graft loss within the first year. This approach ensures equal time risk when evaluating outcomes during the first-year post-transplant.

Statistical analysis

Continuous variables are summarized using medians, 25th and 75th percentiles, and were compared between DCD TA-NRP, DCD DPP, and DBD using Kruskal-Wallis tests. Categorical factors are summarized using frequencies and percentages and compared using Pearson's chi-square tests. Bonferroni-corrected ad-hoc pairwise comparisons were performed when the overall tests suggested a significant difference between at least two of the groups.

The numbers of missing data are listed for each variable in Tables 1 and 2. We used multivariate imputation by chained equations to impute 5 datasets with complete data. The multiple imputation included the following characteristics: recipient age, sex, race/ethnicity, education, primary insurance, body mass index (BMI), disease etiology, last candidate status prior to transplant, diabetes, dialysis between listing and transplant, chronic steroid use, transfusion between listing and transplant, intra-aortic balloon pump (IABP), extracorporeal membrane oxygenation (ECMO), intravenous inotropes, mechanical ventilation, left ventricular assist device (LVAD), cardiac output, serum creatinine, total bilirubin, waitlist time, total ischemic time, donor age, donor sex, donor race/ethnicity, donor BMI, donor history of diabetes, donor history of hypertension, donor heavy alcohol use, Centers for Disease Control and Prevention (CDC) high-risk donor, donor LVEF, donor serum creatinine, deceased donor cause of death, donor/recipient sex match, donor/recipient weight ratio, donor/recipient PHM match, transplant year, graft survival, and post-transplant follow-up time. All models were fitted on each of the 5 imputed datasets and parameter estimates were combined.

To mitigate bias due to differential follow-up time, we truncated follow-up at 2 years and used time-to-event analyses, which account for censoring. We graphed unadjusted Kaplan-Meier graft and patient survival estimates and used Log-Rank tests to compare the three donor type

Table 1 Recipient and Procedure Characteristics

	Overall (N=13,558)		DBD (N=12,185)		DCD DPP (N=899)		DCD TA-NRP (N=474)		
Factor	N Missing	Statistics	N Missing	Statistics	N Missing	Statistics	N Missing	Statistics	p-value
Age at transplant (years)	0	57.0 [46.0, 64.0]	0	57.0 [46.0, 64.0]	0	56.0 [45.0, 63.0]	0	58.0 [47.0, 65.0]	0.086[b]
Age category at transplant (years)	0		0		0		0		0.23[c]
18 - 39		2115 (15.6)		1904 (15.6)		146 (16.2)		65 (13.7)	
40 - 49		2016 (14.9)		1804 (14.8)		140 (15.6)		72 (15.2)	
50 - 59		3986 (29.4)		3594 (29.5)		270 (30.0)		122 (25.7)	
≥60		5441 (40.1)		4883 (40.1)		343 (38.2)		215 (45.4)	
Sex	0		0		0		0		***< 0.001***[c]
Female		3623 (26.7)		3349 (27.5)[2,3]		190 (21.1)[1]		84 (17.7)[1]	
Male		9935 (73.3)		8836 (72.5)		709 (78.9)		390 (82.3)	
Race/ethnicity	39		32		5		2		***< 0.001***[c]
Non-Hispanic White		8033 (59.4)		7124 (58.6)[2,3]		582 (65.1)[1]		327 (69.3)[1]	
Non-Hispanic Black		3342 (24.7)		3064 (25.2)		190 (21.3)		88 (18.6)	
Non-Hispanic Other and Multi-racial		674 (5.0)		635 (5.2)		—		***	
Hispanic		1470 (10.9)		1330 (10.9)		—		—	
Education	519		483		19		17		0.18[c]
High school or less		5343 (41.0)		4824 (41.2)		340 (38.6)		179 (39.2)	
Some college		3497 (26.8)		3146 (26.9)		238 (27.0)		113 (24.7)	
College or more		4199 (32.2)		3732 (31.9)		302 (34.3)		165 (36.1)	
Primary insurance	0		0		0		0		0.18[c]
Private		6252 (46.1)		5605 (46.0)		437 (48.6)		210 (44.3)	
Medicare		4668 (34.4)		4194 (34.4)		306 (34.0)		168 (35.4)	
Medicaid		2043 (15.1)		1859 (15.3)		118 (13.1)		66 (13.9)	
Other		595 (4.4)		527 (4.3)		38 (4.2)		30 (6.3)	
BMI	78	27.6 [24.1, 31.5]	66	27.5 [24.0, 31.4][3]	9	27.8 [24.4, 32.0]	3	28.5 [25.3, 32.2][1]	***< 0.001***[b]
BMI category	78		66		9		3		***< 0.001***[c]
< 25		4192 (31.1)		3821 (31.5)[3]		262 (29.4)		109 (23.1)[1]	
25 - 29.9		4704 (34.9)		4216 (34.8)		312 (35.1)		176 (37.4)	
30 - 34.9		3420 (25.4)		3066 (25.3)		219 (24.6)		135 (28.7)	
≥35		1164 (8.6)		1016 (8.4)		97 (10.9)		51 (10.8)	
Disease etiology	0		0		0		0		0.099[c]
Idiopathic		4994 (36.8)		4483 (36.8)		328 (36.5)		183 (38.6)	
Ischemic		3602 (26.6)		3226 (26.5)		229 (25.5)		147 (31.0)	
Congenital		467 (3.4)		425 (3.5)		28 (3.1)		14 (3.0)	
Other		4495 (33.2)		4051 (33.2)		314 (34.9)		130 (27.4)	
History of cigarette use	0	5563 (41.0)	0	4959 (40.7)	0	389 (43.3)	0	215 (45.4)	***0.048***[c]
Last status prior to transplant	5		5		0		0		***< 0.001***[c]
Adult Status 1		1560 (11.5)		1503 (12.3)[2,3]		42 (4.7)[1,3]		15 (3.2)[1,2]	
Adult Status 2		6921 (51.1)		6383 (52.4)		384 (42.7)		154 (32.5)	

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Table 1 (*Continued*)

	Overall (N=13,558)		DBD (N=12,185)		DCD DPP (N=899)		DCD TA-NRP (N=474)		
Factor	N Missing	Statistics	N Missing	Statistics	N Missing	Statistics	N Missing	Statistics	p-value
Adult Status 3		1862 (13.7)		1632 (13.4)		149 (16.6)		81 (17.1)	
Adult Status 4		2380 (17.6)		2012 (16.5)		222 (24.7)		146 (30.8)	
Adult Status 5-6[4]		830 (6.1)		650 (5.4)		102 (11.3)		78 (16.5)	
Diabetes	3	3957 (29.2)	3	3542 (29.1)	0	265 (29.5)	0	150 (31.6)	0.47[c]
On dialysis between listing and transplant	11	245 (1.8)	11	226 (1.9)	0	—	0	***	0.37[c]
Chronic steroid use	105	644 (4.8)	105	579 (4.8)	0	42 (4.7)	0	23 (4.9)	0.98[c]
Transfusion between listing and transplant	54	2277 (16.9)	54	2090 (17.2)[3]	0	140 (15.6)[3]	0	47 (9.9)[1,2]	***< 0.001***[c]
Infection requiring intravenous antibiotics within 2 weeks prior to transplant	38	1508 (11.2)	36	1432 (11.8)[2,3]	2	50 (5.6)[1]	0	26 (5.5)[1]	***< 0.001***[c]
Intra-aortic balloon pump	0	3458 (25.5)	0	3242 (26.6)[2,3]	0	141 (15.7)[1]	0	75 (15.8)[1]	***< 0.001***[c]
ECMO	0	901 (6.6)	0	868 (7.1)[2,3]	0	—[1]	0	***[1]	***< 0.001***[c]
IV Inotropes	0	5428 (40.0)	0	4964 (40.7)[2,3]	0	311 (34.6)[1]	0	153 (32.3)[1]	***< 0.001***[c]
Mechanical ventilator	0	289 (2.1)	0	276 (2.3)[2]	0	8 (0.89)[1]	0	5 (1.05)	***0.006***[c]
Mechanical circulatory support	0	5262 (38.8)	0	4693 (38.5)[2]	0	393 (43.7)[1]	0	176 (37.1)	***0.006***[c]
Left or right ventricular assist device	230	5237 (39.3)	208	4669 (39.0)[2]	12	392 (44.2)[1]	10	176 (37.9)	***0.008***[c]
Left ventricular assist device	230	5167 (38.8)	208	4604 (38.4)[2]	12	389 (43.9)[1]	10	174 (37.5)	***0.005***[c]
Total artificial heart	230	25 (0.19)	208	—	12	***	10	***	0.54[c]
Cardiac output (L/min)	676	4.2 [3.4, 5.2]	623	4.2 [3.4, 5.2][2]	37	4.3 [3.5, 5.3][1]	16	4.3 [3.6, 5.3]	***0.003***[b]
Blood type	0		0		0		0		***< 0.001***[c]
A		5198 (38.3)		4711 (38.7)[2,3]		317 (35.3)[1]		170 (35.9)[1]	
AB		662 (4.9)		620 (5.1)		30 (3.3)		12 (2.5)	
B		2029 (15.0)		1866 (15.3)		105 (11.7)		58 (12.2)	
O		5669 (41.8)		4988 (40.9)		447 (49.7)		234 (49.4)	
Functional status	702		634		42		26		***< 0.001***[c]
No assistance (80-100%)		916 (7.1)		816 (7.1)[2,3]		72 (8.4)[1,3]		28 (6.3)[1,2]	
Some assistance (50-70%)		2938 (22.9)		2517 (21.8)		245 (28.6)		176 (39.3)	
Total assistance (< 50%)		9002 (70.0)		8218 (71.1)		540 (63.0)		244 (54.5)	
Serum creatinine (mg/mL)	8	1.1 [0.90, 1.4]	8	1.1 [0.90, 1.4]	0	1.1 [0.92, 1.4]	0	1.2 [0.95, 1.4]	0.19[b]
Total bilirubin (mg/mL)	21	0.70 [0.50, 1.1]	19	0.70 [0.50, 1.1]	2	0.70 [0.40, 1.1]	0	0.70 [0.50, 1.00]	0.96[b]
Total bilirubin (mg/mL)	21		19		2		0		0.30[c]
< 1		9477 (70.0)		8507 (69.9)		626 (69.8)		344 (72.6)	
1 - 1.99		3080 (22.8)		2757 (22.7)		220 (24.5)		103 (21.7)	
2 - 3.99		795 (5.9)		732 (6.0)		42 (4.7)		21 (4.4)	
≥4		185 (1.4)		170 (1.4)		***		***	
Predicted heart mass	58	185.1 [158.2, 207.4]	50	184.3 [157.1, 206.6][2,3]	6	188.0 [164.9, 215.0][1,3]	2	196.4 [173.5, 216.7][1,2]	***< 0.001***[b]

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Table 1 (*Continued*)

	Overall (N=13,558)		DBD (N=12,185)		DCD DPP (N=899)		DCD TA-NRP (N=474)		
Factor	N Missing	Statistics	N Missing	Statistics	N Missing	Statistics	N Missing	Statistics	p-value
eGFR (CKD-EPI 2021)	8	72.3 [55.6, 93.5]	8	72.1 [55.4, 93.5]	0	74.1 [56.8, 94.7]	0	72.6 [58.8, 91.0]	0.38[b]
eGFR (CKD-EPI 2021)	8		8		0		0		***0.013***[c]
105+		1785 (13.2)		1624 (13.3)[3]		114 (12.7)		47 (9.9)[1]	
90 - 104		2094 (15.5)		1859 (15.3)		159 (17.7)		76 (16.0)	
75 - 89		2439 (18.0)		2179 (17.9)		168 (18.7)		92 (19.4)	
60 - 74		3097 (22.9)		2763 (22.7)		199 (22.1)		135 (28.5)	
≤60		4135 (30.5)		3752 (30.8)		259 (28.8)		124 (26.2)	
IMPACT score	329	9.0 [6.0, 12.0]	297	9.0 [6.0, 12.0][2,3]	20	8.0 [5.0, 11.0][1]	12	7.0 [5.0, 10.0][1]	***< 0.001***[b]
Transplant year	0		0		0		0		***< 0.001***[c]
2020		2792 (20.6)		2691 (22.1)[2,3]		88 (9.8)[1,3]		13 (2.7)[1,2]	
2021		2853 (21.0)		2667 (21.9)		107 (11.9)		79 (16.7)	
2022		3061 (22.6)		2763 (22.7)		180 (20.0)		118 (24.9)	
2023		3429 (25.3)		2908 (23.9)		354 (39.4)		167 (35.2)	
2024		1423 (10.5)		1156 (9.5)		170 (18.9)		97 (20.5)	
Time on wait list (months)	0		0		0		0		0.13[c]
0 - 5.9		10,860 (80.1)		9774 (80.2)		693 (77.1)		393 (82.9)	
6 - 11.9		1007 (7.4)		890 (7.3)		81 (9.0)		36 (7.6)	
12 - 23.9		831 (6.1)		745 (6.1)		64 (7.1)		22 (4.6)	
≥24		860 (6.3)		776 (6.4)		61 (6.8)		23 (4.9)	
Total ischemic time (minutes)	22	213.0 [178.0, 251.0]	18	210.0 [176.0, 243.0][2]	4	363.0 [300.0, 427.0][1,3]	0	216.0 [164.0, 247.0][2]	***< 0.001***[b]
Steroid induction	0	9641 (71.1)	0	8645 (70.9)[2,3]	0	689 (76.6)[1,3]	0	307 (64.8)[1,2]	***< 0.001***[c]
Thymoglobulin induction	0	2589 (19.1)	0	2388 (19.6)[2,3]	0	133 (14.8)[1]	0	68 (14.3)[1]	***< 0.001***[c]
Basiliximab induction	0	3527 (26.0)	0	3109 (25.5)[2,3]	0	329 (36.6)[1,3]	0	89 (18.8)[1,2]	***< 0.001***[c]
Any induction	0	11,053 (81.5)	0	9931 (81.5)[2,3]	0	771 (85.8)[1,3]	0	351 (74.1)[1,2]	***< 0.001***[c]
Transplant hospital region[4]	0		0		0		0		***< 0.001***[c]
Northeast (Regions 1, 2, 9)		3084 (22.7)		2742 (22.5)[2,3]		263 (29.3)[1,3]		79 (16.7)[1,2]	
Southeast (Regions 3, 11)		3692 (27.2)		3213 (26.4)		329 (36.6)		150 (31.6)	
South Central (Region 4)		1170 (8.6)		1098 (9.0)		36 (4.0)		36 (7.6)	
West (Regions 5, 6, 8)		3565 (26.3)		3193 (26.2)		179 (19.9)		193 (40.7)	
Midwest (Regions 7, 10)		2047 (15.1)		1939 (15.9)		92 (10.2)		16 (3.4)	
Center adult heart transplant volume	0	220.0 [141.0, 303.0]	0	213.0 [130.0, 298.0][2,3]	0	265.0 [213.0, 427.0][1,3]	0	309.0 [213.0, 695.0][1,2]	***< 0.001***[b]
Center adult heart DCD transplant volume	0	15.0 [3.0, 49.0]	0	13.0 [2.0, 43.0][2,3]	0	51.0 [34.0, 134.0][1,3]	0	69.0 [40.0, 251.0][1,2]	***< 0.001***[b]

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Table 1 (*Continued*)

Factor	Overall (N=13,558)		DBD (N=12,185)		DCD DPP (N=899)		DCD TA-NRP (N=474)		p-value
	N Missing	Statistics	N Missing	Statistics	N Missing	Statistics	N Missing	Statistics	
Percent of adult DCD heart transplants	0	7.9 [1.7, 17.5]	0	6.0 [1.5, 16.4][2,3]	0	20.2 [14.5, 30.1][1,3]	0	29.1 [16.4, 36.1][1,2]	***< 0.001***[b]
Center adult heart DCD TA-NRP transplant volume	0	3.0 [0.00, 9.0]	0	2.0 [0.00, 8.0][2,3]	0	7.0 [3.0, 15.0][1,3]	0	54.0 [19.0, 178.0][1,2]	***< 0.001***[b]
Percent of adult DCD TA-NRP heart transplants	0	1.2 [0.00, 2.8]	0	0.91 [0.00, 2.6][2,3]	0	2.5 [1.10, 2.8][1,3]	0	19.6 [11.9, 25.6][1,2]	***< 0.001***[b]

Statistics presented as Median [P25, P75], N (column %).
p-values: b=Kruskal-Wallis test, c=Pearson's chi-square test.
***: Cell suppressed because of count ≤ 10
—: Cell suppressed to avoid back-calculation of other suppressed
Post-hoc pairwise comparisons were done using Bonferroni adjustment.
[1]Significantly different from DBD
[2]Significantly different from DCD DPP
[3]Significantly different from DCD TA-NRP
[4]Categories aggregated due to at least 1 cell count ≤ 10

groups. We used multivariable Cox proportional hazards models to assess the association of donor type with graft and patient survival, adjusting for the same variables included in the multiple imputation models, except graft survival and post-transplant follow-up time. To reduce redundancy and potential multicollinearity, we assessed all covariates using variance inflation factors. Disease etiology and donor/recipient weight ratio were excluded from the final models based on this assessment. We evaluated the interaction between donor type and transplant year to assess whether the association between donor type and survival varied by year.

We utilized logistic regression to evaluate the association of donation type with treated acute rejection before discharge and in-hospital death. We also used logistic regression to assess 1-year post-transplant outcomes, as the follow-up forms record only the administrative date of form rather than the exact timing of each event. These models were adjusted for the same variables used in the Cox models.

Lastly, we conducted sensitivity analyses of the primary outcomes in the subset of transplants performed at centers that completed at least one at least one DCD and at least one TA-NRP transplant during the study period.

All tests were two-tailed and performed at a significance level of 0.05 using SAS 9.4 software (SAS Institute, Cary, NC).

Results

Baseline characteristics

Within the study period, there were 474 (3.5%) DCD TA-NRP, 899 (6.6%) DCD DPP, and 12,185 (89.9%) DBD heart transplants. Baseline recipient characteristics varied between study cohorts (Table 1). DCD TA-NRP recipients were more commonly male (82% DCD TA-NRP, 79% DCD DPP, 73% DBD; $p < 0.001$), were more commonly non-Hispanic White (69%, 65%, 59%; $p < 0.001$), were less likely to have BMI < 25 (23%, 29%, 32%; $p < 0.001$), had fewer preoperative blood transfusions (10%, 16%, 17%; $p < 0.001$), were less likely to have functional status < 50% (55%, 63%, 71%; $p < 0.001$), were less likely to require preoperative inotropes at transplantation (32%, 34%, 41%; $p < 0.001$), and had larger PHM (median 196, 188, 184; $p < 0.001$). DCD TA-NRP was associated with the lowest transplantation rates of Status 1 candidates (3%, 5%, 12%) and highest transplantation rates of Status 5 or 6 candidates (17%, 11%, 5%; $p < 0.001$). Additionally, DCD TA-NRP transplants were more likely to be performed in later years of the study period ($p < 0.001$) and were more likely to be performed in centers located in the West (41%, 20%, 26%; $p < 0.001$).

Donor characteristics varied between study cohorts (Table 2). DCD TA-NRP donors were less likely to be 40 years or older (21%, 19%, 27%; $p < 0.001$), more commonly male (86%, 83%, 71%; $p < 0.001$), more commonly

Table 2 Donor and Donor-recipient Characteristics

	Overall (N=13,558)		DBD (N=12,185)		DCD DPP (N=899)		DCD TA-NRP (N=474)		
Factor	N Missing	Statistics	N Missing	Statistics	N Missing	Statistics	N Missing	Statistics	p-value
Donor age (years)	0	32.0 [25.0, 40.0]	0	33.0 [25.0, 40.0][2,3]	0	31.0 [25.0, 38.0][1]	0	32.0 [24.0, 38.0][1]	***< 0.001***[b]
Donor age (years)	0		0		0		0		***< 0.001***[c]
< 18		631 (4.7)		562 (4.6)[2,3]		45 (5.0)[1]		24 (5.1)[1]	
18 - 39		9365 (69.1)		8332 (68.4)		682 (75.9)		351 (74.1)	
≥40		3562 (26.3)		3291 (27.0)		172 (19.1)		99 (20.9)	
Donor sex	0		0		0		0		***< 0.001***[c]
Female		3800 (28.0)		3580 (29.4)[2,3]		152 (16.9)[1]		68 (14.3)[1]	
Male		9758 (72.0)		8605 (70.6)		747 (83.1)		406 (85.7)	
Donor race/ethnicity	12		8		2		2		***< 0.001***[c]
Non-Hispanic White		8444 (62.3)		7403 (60.8)[2,3]		683 (76.1)[1]		358 (75.8)[1]	
Non-Hispanic Black		2222 (16.4)		2094 (17.2)		—		—	
Non-Hispanic Other and Multi-racial		427 (3.2)		396 (3.3)		—		***	
Hispanic		2453 (18.1)		2284 (18.8)		99 (11.0)		70 (14.8)	
Donor BMI	16	27.1 [23.7, 31.5]	9	27.1 [23.7, 31.5]	1	26.6 [23.4, 31.3]	6	27.0 [23.7, 30.9]	0.11[b]
Donor BMI	16		9		1		6		0.55[c]
< 25		4809 (35.5)		4304 (35.3)		340 (37.9)		165 (35.3)	
25 - 29.9		4388 (32.4)		3947 (32.4)		282 (31.4)		159 (34.0)	
30 - 34.9		2555 (18.9)		2296 (18.9)		167 (18.6)		92 (19.7)	
≥35		1790 (13.2)		1629 (13.4)		109 (12.1)		52 (11.1)	
Donor history of diabetes	199	595 (4.5)	195	548 (4.6)	3	34 (3.8)	1	13 (2.7)	0.10[c]
Donor history of hypertension	211	2133 (16.0)	204	1944 (16.2)[2]	5	117 (13.1)[1]	2	72 (15.3)	***0.043***[c]
Donor cigarette use > 20 pack years	448	1699 (13.0)	421	1543 (13.1)	16	103 (11.7)	11	53 (11.4)	0.29[c]
Donor history of cocaine use	2951	3058 (28.8)	2466	2806 (28.9)	316	160 (27.4)	169	92 (30.2)	0.66[c]
Donor heavy alcohol use	572	2744 (21.1)	531	2381 (20.4)[2,3]	26	238 (27.3)[1]	15	125 (27.2)[1]	***< 0.001***[c]
CDC high-risk donor	0	3591 (26.5)	0	3296 (27.0)[2]	0	185 (20.6)[1]	0	110 (23.2)	***< 0.001***[c]
Donor LVEF %	37	60.0 [57.0, 65.0]	30	60.0 [56.0, 65.0][2,3]	3	62.0 [59.0, 65.0][1]	4	64.5 [60.0, 67.0][1]	***< 0.001***[b]
Donor LVEF % < 45	37	89 (0.66)	30	84 (0.69)	3	3 (0.33)	4	2 (0.43)	0.36[c]
Donor predicted heart mass	0	186.8 [164.9, 207.8]	0	186.0 [163.7, 207.0][2,3]	0	191.9 [173.6, 213.2][1]	0	194.8 [176.8, 214.6][1]	***< 0.001***[b]
Donor serum creatinine (mg/mL)	106	1.00 [0.71, 1.6]	99	1.00 [0.74, 1.7][2,3]	6	0.75 [0.60, 1.00][1]	1	0.74 [0.60, 1.00][1]	***< 0.001***[b]
Deceased donor cause of death	0		0		0		0		***< 0.001***[c]
Anoxia		6560 (48.4)		5884 (48.3)[2,3]		458 (50.9)[1]		218 (46.0)[1]	
Cerebrovascular/Stroke		1604 (11.8)		1502 (12.3)		64 (7.1)		38 (8.0)	
Head trauma		5031 (37.1)		4490 (36.8)		345 (38.4)		196 (41.4)	
Other		363 (2.7)		309 (2.5)		32 (3.6)		22 (4.6)	

(*continued on next page*)

Table 2 (*Continued*)

	Overall (N=13,558)		DBD (N=12,185)		DCD DPP (N=899)		DCD TA-NRP (N=474)		
Factor	N Missing	Statistics	N Missing	Statistics	N Missing	Statistics	N Missing	Statistics	p-value
Donor/recipient are same sex	0	10,897 (80.4)	0	9742 (80.0)[2,3]	0	751 (83.5)[1]	0	404 (85.2)[1]	***< 0.001***[c]
Donor/recipient ABO incompatible	0	***	0	***	0	***	0	***	0.95[c]
Donor/recipient weight ratio	5		5		0		0		***< 0.001***[c]
< 0.8 (> 20% undersized)		1256 (9.3)		1076 (8.8)[2,3]		108 (12.0)[1]		72 (15.2)[1]	
0.8 - 1.2 (within 20% of recipient's weight)		9919 (73.2)		8969 (73.6)		631 (70.2)		319 (67.3)	
> 1.2 (> 20% oversized)		2378 (17.5)		2135 (17.5)		160 (17.8)		83 (17.5)	
1+ A mismatches	1164	11,561 (93.3)	963	10,462 (93.2)	158	695 (93.8)	43	404 (93.7)	0.78[c]
1+ B mismatches	1164	12,139 (97.9)	963	10,996 (98.0)	158	723 (97.6)	43	420 (97.4)	0.57[c]
1+ DR mismatches	1165	11,833 (95.5)	963	10,709 (95.4)	158	707 (95.4)	44	417 (97.0)	0.32[c]
1+ HLA mismatches	1165	12,382 (99.9)	963	11,213 (99.9)	158	740 (99.9)	44	429 (99.8)	0.53[c]
Geodetic distance between donor and transplant hospitals (NM)	4	250.7 [111.1, 422.9]	4	245.9 [110.1, 413.7][2]	0	374.9 [176.7, 593.6][1,3]	0	222.8 [41.4, 426.8][2]	***< 0.001***[b]
Donor/Recipient PHM ratio	58	1.01 [0.92, 1.1]	50	1.01 [0.92, 1.1]	6	1.02 [0.92, 1.1]	2	1.00 [0.91, 1.1]	0.22[b]
Donor/Recipient PHM match (% difference)	58	0.95 [−7.9, 12.7]	50	0.94 [−7.8, 12.7]	6	1.7 [−7.8, 14.2]	2	0.06 [−8.8, 12.1]	0.23[b]

Statistics presented as Median [P25, P75], N (column %).
p-values: b=Kruskal-Wallis test, c=Pearson's chi-square test.
***: Cell suppressed because of count ≤ 10
—: Cell suppressed to avoid back-calculation of other suppressed
Post-hoc pairwise comparisons were done using Bonferroni adjustment.
[1]Significantly different from DBD
[2]Significantly different from DCD DPP
[3]Significantly different from DCD TA-NRP

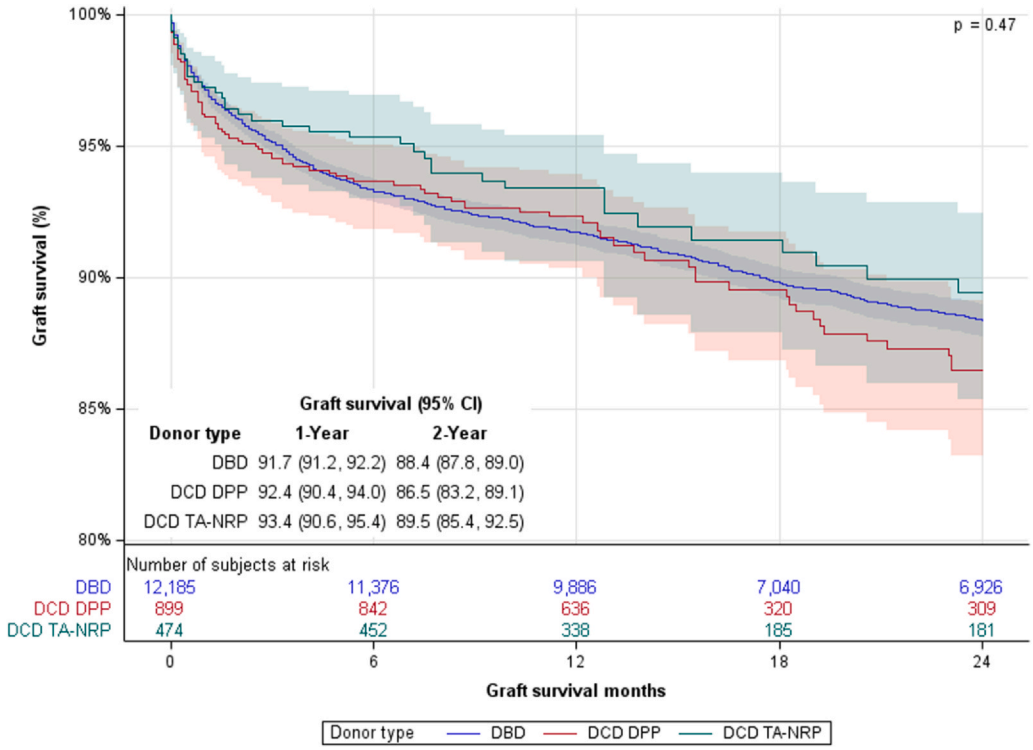

Figure 2 Unadjusted graft survival by donor type.

non-Hispanic White (76%, 76%, 61%; p < 0.001), and more likely to have a history of heavy alcohol use (27%, 27%, 20%; p < 0.001). In addition, TA-NRP hearts were more likely given to same-sex recipients (85%, 84%, 80%; p < 0.001) and recipients with < 0.8 donor/recipient weight ratio (15%, 12%, 9%; p < 0.001). DCD TA-NRP was also associated with the shortest median distance traveled (223 miles, 375, 246; p < 0.001).

DCD TA-NRP was associated with the lowest rate of induction therapy (74%, 86%, 82%; p < 0.001). There was variance in the type of induction agent, but TA-NRP had the lowest utilization rates with all induction agents (Table 1). DBD recovery had the highest rate of thymoglobulin induction (14%, 15%, 20%; p < 0.001) and DCD DPP recovery had the highest rate of basiliximab induction (19%, 37%, 26%; p < 0.001) and steroid induction (65%, 77%, 71%; p < 0.001).

Graft and patient survival

Overall, there were 1372 events of graft loss (death or retransplant) and 1343 deaths during a median follow-up of 2 years [P25, P75: 1, 2]. Follow-up was significantly longer for DBD vs. DCD DPP and DCD TA-NRP (2 [1, 2] vs. 1 [0.5, 2] vs 1 [0.5, 2]; p < 0.001). Graft survival rates (p=0.47) and patient survival rates (p=0.49) were similar across groups (p=0.47) (Figure 2).

There was no significant difference in graft survival between the different donor types and between different DCD procurement methods after adjusting for recipient and donor characteristics [adjusted hazard ratio (aHR) (95% CI): 0.94 (0.73, 1.21) for DCD DPP vs. DBD; 0.98 (0.70, 1.37) for DCD TA-NRP vs. DBD; 1.04 (0.69, 1.56) for DCD TA-NRP vs. DCD DPP]. (Table 3). There was also no significant difference in patient survival between the different donor types after adjusting for recipient and donor characteristics [(aHR) (95% CI): 0.91 (0.71, 1.18) for DCD DPP vs. DBD; 0.96 (0.68, 1.34) for DCD TA-NRP vs. DBD; 1.05 (0.70, 1.58) for DCD TA-NRP vs. DCD DPP]. (Table 3). There was no association between year and graft loss (p=0.33) or year and death (p=0.34). The interaction between donor type and year was not significant (graft survival p=0.37; patient survival p=0.56).

Secondary outcomes

Recipients had a median hospital stay of 17 days post-heart transplantation. During this time, 9.3% had treated acute rejection and 5% died in the hospital, consistent across all groups (Supplemental Table 1). There was no significant difference in the rate of treated acute rejection prior to discharge or in-hospital death between groups after adjusting for recipient and donor characteristics (Table 4).

Supplemental Table 2 summarizes 1-year post-transplant maintenance therapy and outcomes for the subset of subjects with 1-year graft survival. There were no significant differences in the use of tacrolimus or mycophenolate mofetil for maintenance therapy, but steroid utilization rates differed (86%, 86%, 82%; p=0.002), with no difference between DCD TA-NRP and DCD DPP. These results remained consistent after adjusting for recipient and donor characteristics (Table 5). Additionally, there were no significant differences in hospitalizations, CAD, or treated acute rejection during the first-year post-transplant; also consistent after adjustments (Table 5).

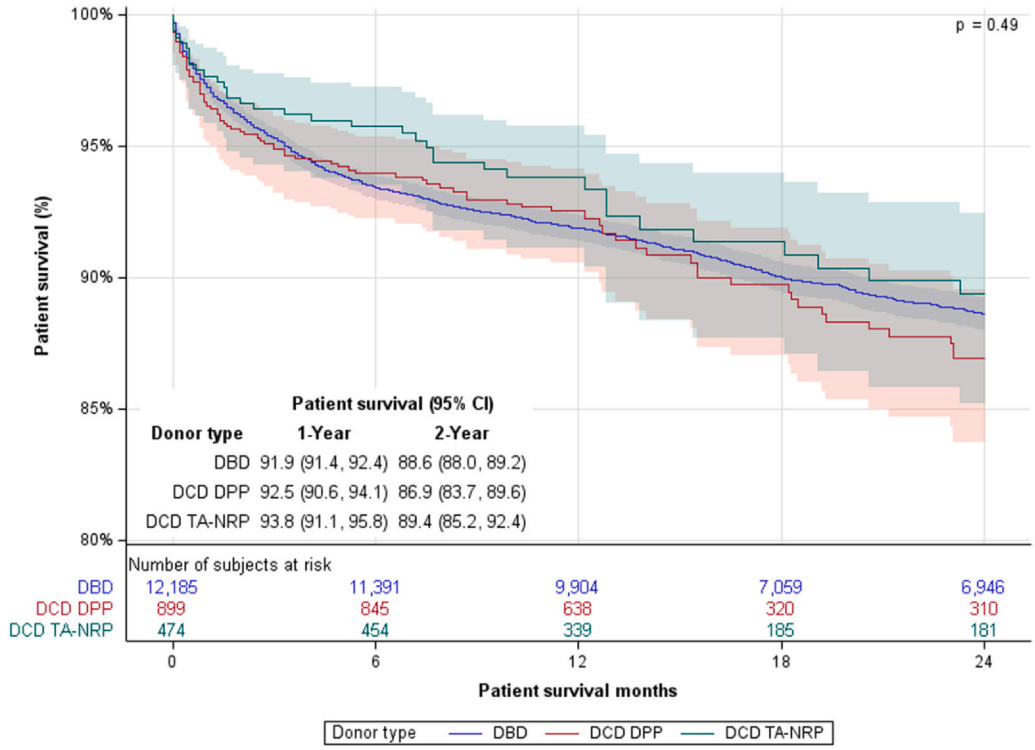

Figure 3 Unadjusted patient survival by donor type.

Sensitivity analyses

Of 135 transplant centers included in the study, 75 (55.6%) performed 1 or more DCD adult transplants and 56 (41.5%) performed one or more DCD TA-NRP adult heart transplants. A total of 10,855 heart transplants performed in these DCD centers; 474 (44%) were TA-NRP, 899 (8.3%) were DPP, and 9482 (87.4%) were DBD. Neither graft nor patient survival were found to be significantly associated with type of donor when restricted to TA-NRP centers (Supplemental Table 3). A total of 9219 heart transplants performed in the DCD TA-NRP centers; 474 (5.1%) were TA-NRP, 839 (9.1%) were DPP, and 7906 (85.8%) were DBD. The percentage of DCD TA-NRP out of all transplants performed ranged from 1.2% to 27.1% with a median of 2.6% (Supplemental Figure 2). Neither graft nor patient survival were found to be significantly associated with type of donor when restricted to DCD TA-NRP centers (Supplemental Table 4).

Discussion

Our results demonstrated that heart transplantation graft and patient survival rates did not significantly vary between DCD TA-NRP, DCD DPP, and DBD recovery. This is the first manuscript to our knowledge examining rates of graft survival after heart transplantation with DCD TA-NRP recovery. Most graft losses resulted in death, with only a few patients (n=29) receiving a re-transplantation. Secondary outcomes, including rates of treated acute rejection, in-

Table 3 Association of Donor Type with Graft Loss and Patient Death

Donor Type Comparison	Unadjusted HR (95% CI)	Adjusted* HR (95%CI)
Outcome = Graft Loss		
DCD DPP vs. DBD	1.06 (0.85, 1.31)	0.94 (0.73, 1.21)
DCD TA-NRP vs. DBD	0.83 (0.60, 1.15)	0.98 (0.70, 1.37)
DCD TA-NRP vs. DCD DPP	0.79 (0.54, 1.16)	1.04 (0.69, 1.56)
Outcome = Patient Death		
DCD DPP vs. DBD	1.04 (0.83, 1.30)	0.91 (0.71, 1.18)
DCD TA-NRP vs. DBD	0.83 (0.59, 1.15)	0.96 (0.68, 1.34)
DCD TA-NRP vs. DCD DPP	0.79 (0.54, 1.17)	1.05 (0.70, 1.58)

HR: hazard ratio; CI: confidence interval

*Adjusted for recipient age, sex, race/ethnicity, education, primary insurance, BMI, last status prior to transplant, diabetes, on dialysis between listing and transplant, chronic steroid use, transfusion between listing and transplant, intra-aortic balloon pump, ECMO, IV inotropes, mechanical ventilator, left ventricular assist device, cardiac output, serum creatinine, total bilirubin, time on wait list, total ischemic time, donor age, donor sex, donor race/ethnicity, donor BMI, donor history of diabetes, donor history of hypertension, donor heavy alcohol use, CDC high-risk donor, donor LVEF, donor serum creatinine, deceased donor cause of death, donor/recipient are same sex, donor/recipient PHM match, transplant year

Table 4 Association of Donor Type with In-hospital Outcomes Following-heart Transplant

Donor Type Comparison	Unadjusted OR (95%CI)	Adjusted* OR (95%CI)
Outcome = Treated acute rejection before discharge		
DCD DPP vs. DBD	0.90 (0.71, 1.15)	0.94 (0.71, 1.23)
DCD TA-NRP vs. DBD	0.91 (0.66, 1.26)	1.06 (0.76, 1.49)
DCD TA-NRP vs. DCD DPP	1.01 (0.68, 1.50)	1.14 (0.75, 1.73)
Outcome = In-hospital death		
DCD DPP vs. DBD	1.11 (0.81, 1.52)	0.84 (0.58, 1.21)
DCD TA-NRP vs. DBD	0.78 (0.48, 1.28)	0.90 (0.54, 1.50)
DCD TA-NRP vs. DCD DPP	0.71 (0.40, 1.25)	1.08 (0.59, 1.97)

OR: odds ratio; CI: confidence interval

*Adjusted for recipient age, sex, race/ethnicity, education, primary insurance, BMI, disease etiology, last status prior to transplant, diabetes, on dialysis between listing and transplant, chronic steroid use, transfusion between listing and transplant, intra-aortic balloon pump, ECMO, IV inotropes, mechanical ventilator, left ventricular assist device, cardiac output, serum creatinine, total bilirubin, time on wait list, total ischemic time, donor age, donor sex, donor race/ethnicity, donor BMI, donor history of diabetes, donor history of hypertension, donor heavy alcohol use, CDC high-risk donor, donor LVEF, donor serum creatinine, deceased donor cause of death, donor/recipient are same sex, donor/recipient PHM match, transplant year

hospital mortality, and readmissions, did not differ between cohorts on adjusted analysis. Donor and recipient characteristics varied significantly, with DCD TA-NRP recipients having lower listing statuses, fewer transfusions pre-transplant, fewer preoperative infections, lower rates of preoperative inotropes or mechanical circulatory support, and lower rates of induction therapy, reflecting a healthier DCD TA-NRP recipient population and suggesting

Table 5 Association of Donor Type with One-year Post-heart Transplant Outcomes

Donor Type Comparison	Unadjusted OR (95%CI)	Adjusted* OR (95%CI)
Outcome = Hospitalized within first year post-transplant		
DCD DPP vs. DBD	0.85 (0.72, 1.00)	0.82 (0.68, 0.99)
DCD TA-NRP vs. DBD	0.91 (0.73, 1.14)	0.98 (0.78, 1.24)
DCD TA-NRP vs. DCD DPP	1.08 (0.82, 1.41)	1.20 (0.90, 1.59)
Outcome = Coronary artery disease within first year post-transplant		
DCD DPP vs. DBD	0.90 (0.63, 1.28)	1.12 (0.76, 1.65)
DCD TA-NRP vs. DBD	1.15 (0.75, 1.77)	1.11 (0.71, 1.74)
DCD TA-NRP vs. DCD DPP	1.28 (0.74, 2.20)	0.99 (0.56, 1.76)
Outcome = Treated acute rejection within first year post-transplant		
DCD DPP vs. DBD	1.39 (1.04, 1.84)	1.18 (0.85, 1.65)
DCD TA-NRP vs. DBD	1.09 (0.72, 1.67)	1.13 (0.72, 1.75)
DCD TA-NRP vs. DCD DPP	0.79 (0.48, 1.30)	0.95 (0.56, 1.62)
Outcome = Tacrolimus maintenance therapy		
DCD DPP vs. DBD	0.76 (0.49, 1.19)	0.84 (0.50, 1.41)
DCD TA-NRP vs. DBD	1.30 (0.61, 2.78)	1.00 (0.46, 2.19)
DCD TA-NRP vs. DCD DPP	1.71 (0.72, 4.04)	1.19 (0.48, 2.95)
Outcome = MMF maintenance therapy		
DCD DPP vs. DBD	1.06 (0.74, 1.53)	0.92 (0.61, 1.39)
DCD TA-NRP vs. DBD	1.75 (0.95, 3.20)	1.56 (0.84, 2.90)
DCD TA-NRP vs. DCD DPP	1.64 (0.82, 3.29)	1.69 (0.82, 3.48)
Outcome = Steroid maintenance therapy		
DCD DPP vs. DBD	1.39 (1.10, 1.76)	1.41 (1.08, 1.83)
DCD TA-NRP vs. DBD	1.45 (1.05, 2.00)	1.48 (1.06, 2.06)
DCD TA-NRP vs. DCD DPP	1.04 (0.70, 1.54)	1.05 (0.70, 1.58)
Outcome = Steroids for antirejection		
DCD DPP vs. DBD	1.37 (1.01, 1.87)	1.14 (0.80, 1.63)
DCD TA-NRP vs. DBD	1.11 (0.70, 1.73)	1.12 (0.70, 1.79)
DCD TA-NRP vs. DCD DPP	0.80 (0.47, 1.37)	0.98 (0.56, 1.73)

OR: odds ratio; CI: confidence interval

*Adjusted for recipient age, sex, race/ethnicity, education, primary insurance, BMI, last status prior to transplant, diabetes, on dialysis between listing and transplant, chronic steroid use, transfusion between listing and transplant, intra-aortic balloon pump, ECMO, IV inotropes, mechanical ventilator, left ventricular assist device, cardiac output, serum creatinine, total bilirubin, time on wait list, total ischemic time, donor age, donor sex, donor race/ethnicity, donor BMI, donor history of diabetes, donor history of hypertension, donor heavy alcohol use, CDC high-risk donor, donor LVEF, donor serum creatinine, deceased donor cause of death, donor/recipient are same sex, donor/recipient PHM match, transplant year

anticipated lower risk of rejection; however, study outcomes did not significantly vary when adjusting for these differences.

Graft survival has been attributed to multiple factors, including advanced recipient age (> 50 years) or donor age (> 55 years), Black recipients, valvular cardiomyopathy, congenital heart disease, recipient history of diabetes, mechanical ventilation, durable LVAD, ECMO, renal or liver dysfunction, positive cytomegalovirus serologies, female donors, and prolonged ischemic time.[12–14] Our multivariable model adjusted for a multitude of these variables and found no significant difference in graft survival rates that could be attributed to recovery method.

The growing literature on DCD TA-NRP recovery in heart transplantation has been promising regarding early graft function, rejection, and patient survival. Multiple studies utilizing the UNOS database have demonstrated comparable rates of early and long-term survival between recovery methods, suggesting that all these recovery methods are acceptable for heart transplantation.[4,15,16] Chen et al. and Li et al. demonstrated higher rates of acute treated rejection with DCD recovery, although no differences were found between DCD DPP and DCD TA-NRP recovery, and Cho et al. demonstrated similarly higher rates of severe primary graft dysfunction (PGD) at 24 h with both DCD cohorts compared to the DBD cohort, although severe PGD rates were similar between all recovery methods at 72 h[7,17,18] The higher acute rejection rates and severe PGD rates have been suggested to be related to the stronger immune response from the healthier DCD recipients and upregulated inflammation and oxidative stress from warm ischemia time and machine perfusion.[7,18] Our results did not demonstrate a significant difference in rejection rates which may be related to a more modern cohort, potentially reflecting greater experience and optimized management of DCD recipients to decrease rejection. While we did not examine severe PGD rates, our results are encouraging that higher rates of severe PGD noted with DCD recovery may not translate to differences in long-term graft survival, although future studies should continue to monitor this trend.

TA-NRP recovery of DCD heart allografts has had varying acceptance across the United States, as demonstrated by our findings of greater adoption in the western states. TA-NRP provides additional benefits of decreased costs and increased organ yield with DCD recovery, which can help address all solid organ shortages for transplantation.[2,3,19] Disparities in heart transplantation, similar to other solid organ transplantation and other disease processes, have been well documented, and our results demonstrate fewer Black recipients and a less sick recipient population among our DCD TA-NRP cohort, which is concordant with the existing DCD TA-NRP literature.[4,16,20,21] As our adjusted analyses accounted for these variables and did not demonstrate a difference in post-transplant outcomes, this potentially suggests a selection bias in selecting DCD TA-NRP recovery for non-Black candidates or candidates with lower listing status and warrants further investigation. While the authors of the current study are biased in favor of DCD TA-NRP utilization, we believe these results add to the growing body of literature supporting greater utilization of TA-NRP recovery of DCD allografts.

Limitations of our study include the potential for database errors in data reporting and lack of granularity. The SRTR does not identify DCD recovery or storage methods, and our identification of DPP and TA-NRP by time cutoffs is subject to error. The exclusion of cases with intermediate durations (30–40 min) may reduce misclassification but could also introduce selection bias; however, given the limited number of excluded cases, this is unlikely to have meaningfully impacted the results. Based on our study period, it is likely that the DCD DPP donor hearts included were perfused with normothermic machine perfusion, so our results do not include results of the newly emerged hypothermic oxygenated perfusion, which demonstrates promise and should be a future area of study.[22,23] Centers using TA-NRP may be systematically different as well. Granularity of data on rejection, which could contribute to overall graft survival rates, is limited in database studies due to limited reporting at 6 months and 1 year with no requirement for centers to provide follow up data after documented graft loss. Additionally, there may be other underlying donor or recipient characteristics, such as calculated panel reactive antibody, not codified into the database. More single-center studies to provide this granularity on acute and chronic rejection rates after DCD TA-NRP recovery may be warranted. Given the more recent adoption of DCD heart transplantation, patients in this group had shorter follow-up and may have been treated at centers with less cumulative experience; these factors may influence outcomes. There was also limited power to detect differences for some outcomes so our results will need to be confirmed with additional data.

In summary, our results add to the growing field of literature supporting DCD TA-NRP recovery of heart transplants with comparable graft and patient survival. While future studies should continue to evaluate more longitudinal graft and patient survival outcomes related to DCD TA-NRP recovery, these early results are promising that TA-NRP remains a viable method to recover DCD hearts without negatively impacting transplant outcomes.

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The other authors have no financial conflicts of interest.

Declaration of Competing Interest

The authors declare the following financial interests/personal relationships which may be considered as potential competing interests: Jordan R.H. Hoffman, MD, MPH reports a relationship with Donor Alliance Inc that includes: board membership. Jesse D. Schold, PhD reports a relationship with National Institutes of Health that includes: funding grants. Jesse D. Schold, PhD reports a relationship with One Legacy Foundation that includes: funding grants. Jesse D. Schold, PhD reports a relationship with Sanofi Inc. that includes: speaking and lecture fees. Jesse D. Schold, PhD reports a relationship with Novartis that includes: speaking and lecture fees. Jesse D. Schold, PhD reports a relationship with Veloxis Pharmaceuticals Inc that includes: speaking and lecture fees. Jesse D. Schold, PhD reports a relationship with eGenesis that includes: speaking and lecture fees. Jesse D. Schold, PhD reports a relationship with Kidney Transplant Collaborative that includes: funding grants. Jesse D. Schold, PhD reports a relationship with US Department of Defense that includes: funding grants. Jesse D. Schold, PhD reports a relationship with Kamada, Inc. that includes: funding grants. Jesse D. Schold, PhD reports a relationship with Centers for Medicare and Medicaid Services that includes: travel reimbursement. Jesse D. Schold, PhD reports a relationship with American Society of Transplantation that includes: travel reimbursement. Jesse D. Schold, PhD reports a relationship with Bristol Myers Squibb Co that includes: board membership. Jesse D. Schold, PhD reports a relationship with NextCure Inc that includes: board membership. Jesse D. Schold, PhD reports a relationship with CSL Behring that includes: board membership. Jesse D. Schold, PhD reports a relationship with United Network for Organ Sharing that includes: board membership and non-financial support. Rocio Lopez, MS reports a relationship with Gift of Life Foundation that includes: funding grants. Rocio Lopez, MS reports a relationship with One Legacy that includes: funding grants. Rocio Lopez, MS reports a relationship with National Institutes of Health that includes: funding grants. Rocio Lopez, MS reports a relationship with Association of Organ Procurement Organizations that includes: speaking and lecture fees and travel reimbursement. If there are other authors, they declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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Appendix A. Supporting information

Supplemental data associated with this article can be found in the online version at doi:10.1016/j.jhlto.2025.100470.

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