



ORIGINAL CLINICAL SCIENCE

A comparison of DCD heart transplantation in Europe and the United States: A multi-center, retrospective study

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BACKGROUND: Donation after the circulatory determination of death (DCD) heart transplantation (HT) is becoming more widely adopted across the United States (US) and Europe.

OBJECTIVE: This study compared donor and recipient demographics, intraoperative parameters, and outcomes between DCD HT centers in Europe and the US that contributed to the Outcomes after DCD Cardiac Transplantation Database.

METHODS: This was a retrospective observational study across 22 HT centers in Belgium, Spain, the United Kingdom (UK), and the US. All patients undergoing DCD HT at participating centers, from the start of each center's DCD program through 01/01/2023, were included with censor date 01/01/2024. The primary outcome was 1-year survival. Secondary outcomes included severe primary graft dysfunction and incidence of acute cellular rejection.

RESULTS: Data from 223 patients in Europe and 281 in the US were analyzed. DCD donors in Europe were significantly older (37 years vs 28 years; $p < 0.001$). Recipients in Europe had inferior 1-year survival (86.6% vs 91.8%; $p = 0.043$), but 1-month and 3-years survival were similar. 1-year survival in the direct procurement and preservation (DPP) cohort was significantly higher in the US group (91.2% vs 82.6%; $p = 0.02$). In the thoraco-abdominal normothermic regional perfusion (taNRP) cohort 1-year survival was similar between Europe and the US. Recipients in Europe had higher use of mechanical circulatory assist post-transplant (17.9% vs 11%; $p = 0.03$).

CONCLUSION: This study further confirms the safety and efficacy of DCD HT across centers in the US and Europe, despite important differences in donor and recipient demographics and clinical outcomes. Continued collection of international data may identify opportunities to improve outcomes.

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Background

Heart transplantation (HT) is an excellent treatment for carefully selected patients with advanced heart failure refractory to medical treatment.^{1,2} However, HT is limited by a shortage of suitable donor hearts, which results in unacceptably high waiting list mortality.^{3,4} The use of extended criteria donors, ex-situ machine perfusion, and donation after the circulatory determination of death (DCD) hearts have all shown promise in increasing the number of transplants performed.⁵⁻⁷ Utilization of hearts from DCD donors is estimated to have increased the number of transplants by 23% to 30% across Europe and participating centers in the US.^{8,9}

The first HT performed in 1967 was from a DCD donor.¹⁰ From this point on, transplantation utilized hearts obtained from donors declared dead by neurological criteria or donors after brain death (DBD). Adult DCD HT was reintroduced into clinical practice in 2014 and since then has become widely adopted across Australia, Austria, Belgium, Italy, the Netherlands, Spain, Switzerland, the United Kingdom (UK), and the United States (US).^{8,11-16}

All DCD hearts undergo a period of warm ischemia during the agonal phase between withdrawal of life-sustaining treatment and confirmation of death by circulatory criteria. The hearts are then either perfused in-situ by thoraco-abdominal normothermic regional perfusion (taNRP) or perfused ex-situ by direct procurement and perfusion (DPP).¹⁷⁻¹⁹

There are significant differences in donor demographics between the US and Europe in DBD HT, including a higher donor heart utilization rate in Europe with greater use of hearts from older donors and with more cardiovascular risk

factors, compared to the US.^{20,21} However, there has been no comparison of DCD HT between Europe and the US.

This study aims to compare donor and recipient demographics, operative characteristics, and outcomes for DCD HT in the US to those performed in Europe (Belgium, Spain, and the UK).

Methods

The study design and process of participant selection have been previously described.¹⁹ Consecutive patients who underwent DCD HT at participating centers between February 28, 2015, and January 1, 2023, were enrolled. Follow-up was censored on January 1, 2024. The ODDCAT (Outcomes after DCD Cardiac Transplantation) international DCD heart transplant database includes data from 22 centers across Belgium (2), Spain (11), the UK (2) and the United States (7). The full list of centers is available in the supplement.

Primary and secondary outcomes

The primary outcome was survival at 1-year.

Secondary outcomes included: (i) 3-month survival, (ii) 3-year survival, (iii) severe primary graft dysfunction (PGD) defined as the requirement for mechanical circulatory support (MCS) post-transplant as per the 2014 International Society of Heart and Lung Transplantation (ISHLT) consensus statement, (iv) biopsy-proven acute cellular rejection (ACR) grade 2R or above as defined by the International Society of Heart and Lung Transplantation criteria,^{22,23} (v) duration of post-transplant mechanical

ventilation, (vi) days in the intensive care unit, (vii) estimated glomerular filtration rate at 1-year after HT, and (viii) left ventricular ejection fraction and tricuspid annular plane systolic excursion assessed on echocardiography at 1 month and 1 year post-transplant.

Statistical analysis

Continuous variables were summarized as medians and interquartile ranges and are reported as median [Q1-Q3]. Group comparisons for continuous variables were performed using the Mann-Whitney *U* test to account for non-normal distributions. Categorical variables were expressed as proportions, with between-group differences assessed using Fisher's exact test. Statistical significance for the primary outcome was set at a 2-sided 5% level. All analyses were conducted in Python (v.3.12.1), with the pandas(v.2.1.4), SciPy(v.1.11.4), and lifelines (v.0.28.0) libraries, with the survival (v.3.7-0) library from (v.R4.4.1), imported with rpy2.²⁴⁻²⁶

Post-transplant survival was evaluated using the Kaplan-Meier estimator. Time-to-event was defined as the interval from transplantation to death or re-transplantation. Outcomes were censored at the end of follow-up. Survival curves were generated for the DPP and taNRP groups, with overall survival differences assessed with the log-rank test. Group differences at specific time points were evaluated using a log (-log) transformed survival curve with a chi-squared test.²⁷

To estimate risk factors for acute PGD, we fitted a mixed-effects logistic regression model with a random intercept for transplant center to account for within-center clustering and included prespecified covariates as fixed effects. Models were fit using the glmer function from R (from the lme4 library), and results are reported as odds ratios with 95% confidence intervals.

To compare regional differences in ACR, we evaluated: (i) the proportion of patients who developed ≥ 1 episode of ACR by 1 year, using a chi-squared test (for patients with complete 1-year follow-up); (ii) the total number of biopsy-proven ACR episodes within the first year; and (iii) rejection burden normalized to surveillance intensity (events per biopsy in the first year). Further information can be found in the supplement.

A mixed-effects Cox proportional hazards model was fitted to assess associations between predictor variables and both overall survival and time to ACR events. To account for unobserved heterogeneity between centers, a gamma-distributed frailty term was included to model random effects by center, implemented using the coxph function from the survival package. The proportional hazards assumption was tested using the Schoenfeld residuals method.

Further to this, analyses were performed using complete-case data for the variables included in each model (i.e., participants with missing values in any model covariate were excluded from that model).

Ethics

Centers in the study had appropriate IRB approval to participate. These data were anonymous, and the need for

informed consent was therefore waived. Centers contributing to the study operated under guidelines of their local jurisdictions.

Results

During the study period, 223 patients received a DCD HT in participating European centers and 281 in US centers.

Donor data

Table 1 demonstrates donor demographics, according to region. There was a significantly higher proportion of male DCD donors in the US (88.6% vs 77.6%, $p = 0.001$). In comparison to European donors, they were significantly taller (178 cm vs 175 cm, $p = 0.006$), heavier (83 kg vs 77 kg, $p = 0.001$), and younger (28 years vs 37 years, $p < 0.001$). The US donors were more likely to die from trauma (42.3% vs 21.5%) and anoxia (34.8% vs 22%) and less likely to die from stroke (14.6% vs 42.6%). The proportion of DCD HT performed with hearts recovered by taNRP (40.8% vs 47%) and DPP (59.2% vs 53%) were similar between Europe and the US.

A greater number of kidneys (1.9 vs 1.71 per donor, $p = 0.016$), livers (0.76 vs 0.62 per donor, $p = 0.001$) and lungs (0.5 vs 0.33 per donor, $p = 0.017$) were transplanted from US DCD heart donors.

Supplementary Tables 1 and 2 summarize detailed donor demographics for taNRP DCD HTs and DPP DCD HTs, respectively, according to region.

Operative data

Table 2 details intraoperative data for DCD HT performed in the US and European centers. In US donors, the FWIT was significantly shorter (12 vs 16 min, $p < 0.001$), but significantly longer FCIT (32.5 vs 12 min, $p < 0.001$) and FTIT (33 vs 23 min, $p < 0.001$) were seen. US donors had a longer time on static cold storage (152.5 vs 80 min, $p < 0.001$), but there was no significant difference in time on normothermic ex situ perfusion. Further information can be found in the supplement.

Recipient demographics

Table 2 summarizes the recipient demographics. Recipients in the US were significantly older than those in Europe (56 vs 52 years, $p < 0.001$) and were more likely to have diabetes (54.1% vs 16.1%, $p < 0.001$). US recipients had a significantly higher utilization of pre-transplant MCS overall (39.9% vs 21.1%, $p < 0.001$) and in the taNRP and DPP subgroups (**Supplementary Tables 3 and 4**).

Recipient outcomes

The US cohort had significantly higher survival at 1-year (91.8% vs 86.6%, $p = 0.043$) for all DCD HT recipients.

Table 1 DCD Donor Characteristics

Metric	US	US (Count)	Europe	Europe (Count)	p-value
Height (cm)	178.00 [170.2-183.0]	281 (100.0%)	175.00 [170.0-180.0]	223 (100.0%)	0.006
Weight (kgs)	83.00 [71.2-95.8]	281 (100.0%)	77.00 [70.0-90.0]	223 (100.0%)	0.001
Age (years)	28.00 [23.0-34.0]	267 (95.0%)	37.00 [29.0-45.0]	223 (100.0%)	< 0.001
Female	32 (11.39%)	281	50 (22.4%)	223	0.001
Donor: recipient sex					
M:M (%)	74.38%		66.37%		0.061
M:F	14.23%		11.21%		0.35
F:M	3.56%		10.31%		0.003
F:F	7.83%		12.11%		0.13
Donor predicted heart mass (g)	199.22 [176.5-220.6]	267 (95.0%)	186.59 [166.1-203.9]	222 (99.6%)	< 0.001
Median time from transplant to data collection (days)	789.00 [599.0-1083.0]	281 (100.0%)	1272.00 [665.5-2029.5]	223 (100.0%)	< 0.001
Pre-withdrawal left ventricular ejection fraction (%)	60.00 [60.0-65.0]	267 (95.0%)	61.00 [55.0-65.0]	187 (83.9%)	0.348
Number of kidneys transplanted per donor	1.9	238 (84.7%)	1.71	214 (96.0%)	0.016
Number of livers transplanted per donor	0.76	238 (84.7%)	0.62	214 (96.0%)	0.001
Number of lungs transplanted per donor	0.5	238 (84.7%)	0.33	213 (95.5%)	0.017
Donor cause of death		281 (100%)		223 (100%)	
Trauma	119 (42.3%)		48 (21.5%)		
Stroke	41 (14.6%)		95 (42.6%)		
Anoxia	98 (34.8%)		49 (22.0%)		
Other	23 (8.2%)		31 (13.9%)		
Race		239 (85.1%)		199 (89.2%)	
White	178 (63.3%)		188 (84.3%)		
Black	33 (11.7%)		3 (1.3%)		
Asian	1 (0.4%)		2 (0.9%)		
Hispanic	26 (9.3%)				
Other	1 (0.4%)		3 (1.3%)		
Mixed			3 (1.3%)		
Unknown	42 (14.9%)		24 (10.8%)		

The characteristics of DCD donors.

However, there was no difference in survival at 30-days (97.5% vs 95.5%) or 3-years (79.8% vs 82%) between the groups. Overall survival was not significantly different between regions ($p = 0.69$) (Figure 1). A mixed-effect model for survival did not demonstrate region to be a significant predictor for overall survival (Figure 2). There was no significant difference in overall survival in either the taNRP or DPP subgroups, comparing US vs European transplants (Supplementary Figures 1 and 2). Location was not a significant predictor of survival in mixed effects models in the DPP subgroup but was a significant predictor in the taNRP subgroup (Supplementary Figures 3 and 4). There was no difference in survival at any time point in the taNRP subgroup; however, US recipients in the DPP group had significantly better survival at 1-year than their European counterparts (91.9% vs 82.6%, $p = 0.021$).

European recipients had significantly higher use of post-transplant MCS support (17.9% vs 11%, $p = 0.03$). However, after adjusting for covariates (including donor and recipient age, pretransplant inotropic support, pre-transplant MCS, predicted heart mass ratios, and female to male transplant), a logistic regression model did not show

location to be a significant predictor for MCS use post-transplant (Figure 3).

There was no significant difference in the development of severe PGD in the taNRP group by region (6.8% in the US vs 7.7% in Europe, $p = 0.61$) (Supplementary Table 5). However, in the DPP subgroup there was a significantly higher incidence of severe PGD in Europe compared to the US (24.2% vs 14.8%, $p = 0.049$) (Supplementary Table 6). However, logistic regression models for PGD in the taNRP and DPP subgroups did not show location to be a predictor for the development of PGD for either technique (Supplementary Figures 5 and 6).

Immunological data

Table 3 shows the immunological data for HT recipients by region. Further information can be found in the supplement.

We observed no significant difference in rejection-free survival between patients transplanted in the US vs Europe (Figure 4). Moreover, a mixed-effect model did not demonstrate region to be a significant predictor for acute

Table 2 Intraoperative Data & Recipient Demographics

Metric	US	Count Number (%)	Europe	Count Number (%)	p-values
<i>Intraoperative parameters*</i>					
Functional warm ischemic time (min)	12.00 [10.0-17.0]	270 (96.1%)	16.00 [13.0-20.0]	174 (78.0%)	< 0.001
Functional cold ischemic time (min)**	32.50 [27.0-38.8]	134 (89.9%)	12.00 [9.0-15.0]	105 (79.5%)	< 0.001
Functional total ischemic time (min)	33.00 [13.5-44.5]	267 (95.0%)	23.00 [16.0-27.0]	167 (74.9%)	< 0.001
Static cold storage (min)	152.50 [105.8-184.5]	128 (45.6%)	80.00 [54.8-148.5]	72 (32.3%)	< 0.001
Time on the OCS (min)	263.25 [216.0-310.8]	154 (54.8%)	245.00 [207.0-300.0]	137 (61.4%)	0.111
<i>Method</i>					0.1764
Number retrieved with taNRP (%)	132 (47%)		91 (40.8%)		
Number retrieved with DPP (%)	149 (53%)		132 (59.2%)		
<i>Recipient demographics</i>					
Age (years)	56.00 [47.0-63.0]	265 (94.3%)	52.00 [42.5-60.0]	223 (100.0%)	< 0.001
Sex (F%)	22.06%	62 (22.1%)	23.32%	52 (23.3%)	0.749
Height (cm)	175.30 [170.2-182.9]	281 (100.0%)	172.00 [165.5-178.5]	223 (100.0%)	< 0.001
Weight (kg)	92.20 [80.3-108.4]	281 (100.0%)	75.00 [64.0-86.8]	223 (100.0%)	< 0.001
Diabetes	152 (54.09%)	281 (100.0%)	16.14%	220 (98.7%)	< 0.001
Recipient pulmonary vascular resistance (wood units)	2.00 [1.4-2.9]	258 (91.8%)	1.90 [1.4-2.6]	186 (83.4%)	0.156
Recipient predicted heart mass (g)	202.93 [178.9-229.2]	265 (94.3%)	179.54 [151.6-200.4]	223 (100.0%)	< 0.001
Ratio of donor to recipient predicted heart mass (%)	0.99 [0.9-1.1]	265 (94.3%)	1.03 [1-1.2]	222 (99.6%)	< 0.001
Race		278 (98.9%)		205 (91.9%)	
White	184 (65.7%)		170 (76.9%)		
Black	74 (26.4%)		7 (3.2%)		
Asian	3 (1.1%)		13 (5.9%)		
Hispanic	13 (4.6%)		4 (1.8%)		
American Indian	2 (0.7%)				
Other			7 (3.2%)		
Mixed	1 (0.4%)		2 (0.9%)		
Unknown	3 (1.1%)		18 (8.1%)		
<i>Recipient cause of heart failure</i>					
Dilated	158 (56.2%)		105 (47.1%)		
Ischemic	84 (29.9%)		58 (26.0%)		
Other	25 (8.9%)		33 (14.8%)		
Hypertrophic	11 (3.9%)		27 (12.1%)		
Unknown	3 (1.1%)				
Pre-transplant inotropic support (% of patients on at least 1 inotrope)	94 (33.5%)	281 (100.0%)	66 (29.9%)	221 (99.1%)	0.44
Number of patients requiring MCS pre-transplant (%) (excluding intra-aortic balloon pump)	112 (39.9%)	281 (100.0%)	47 (21.1%)	223 (100.0%)	< 0.001
LVAD	105 (93.8%)		34 (72.3%)		
BIVAD	2 (1.8%)		10 (21.3%)		
ECMO	3 (2.7%)		3 (6.4%)		
TAH	1 (0.9%)				
RVAD	1 (0.9%)				

Intraoperative parameters and recipient demographics of DCD patients across both the US and Europe.

Abbreviations: BIVAD, biventricular assist device; ECMO, extracorporeal membrane oxygenation; LVAD, left ventricular assist device; RVAD, right ventricular assist device; TAH, total artificial heart.

*The definition of these ischemic times can be found in the supplement.

** Only DPP cases have a FCIT; therefore, the count here is calculated as the number - 134/ the total number of DPP, which in the US was 149 and in Europe was 132.

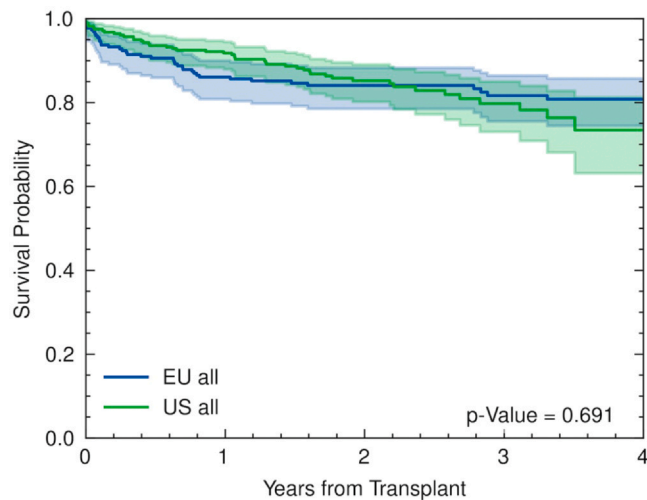


Figure 1 *Kaplan Meier survival curve comparing survival of DCD recipients between the US & Europe.* KM survival curves comparing survival of US and European DCD heart recipients with the numbers at risk shown in the table below. p -value = 0.69. There was no significant difference in survival between these 2 groups.

rejection (Figure 5). Additionally, no significant difference was observed between the rates of biopsy-proven ACR in the US and Europe (0.32 vs 0.22, $p = 1$). Further analysis comparing rejection rates and immunosuppression regimes in DPP and taNRP subgroups are summarized in [Supplementary Tables 5 and 6](#). There was no significant difference in survival between Europe and the US associated with either retrieval technique, nor was location a predictor for rejection ([Supplementary Figures 7–10](#)).

Center-level effects

Center-level clustering was modest in the adjusted mixed-effects models. In the mixed-effects Cox models (shared gamma frailty for center), the center frailty term did not reach statistical significance for overall survival ($p = 0.057$) or rejection-free survival ($p = 0.944$), while the mixed-effects logistic model for acute PGD yielded an intraclass correlation coefficient (ICC) of 0.048, indicating that ~5% of the residual variation in PGD risk was attributable to between-center differences.

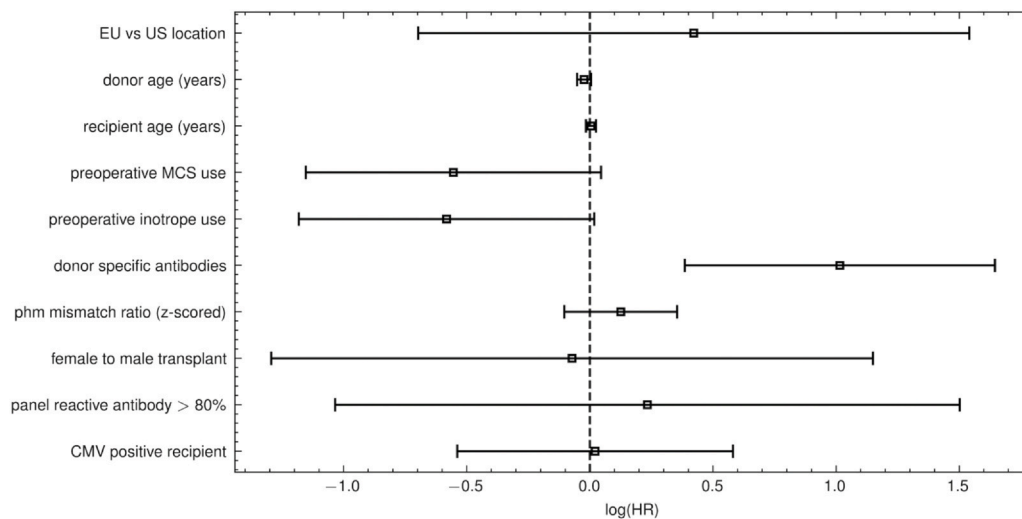


Figure 2 *Forest plot demonstrating the relationship between selected predictors and overall post-transplant survival.* A forest plot demonstrating the relationship between selected predictors and overall transplant survival. $N = 412$, after accounting for missing data.

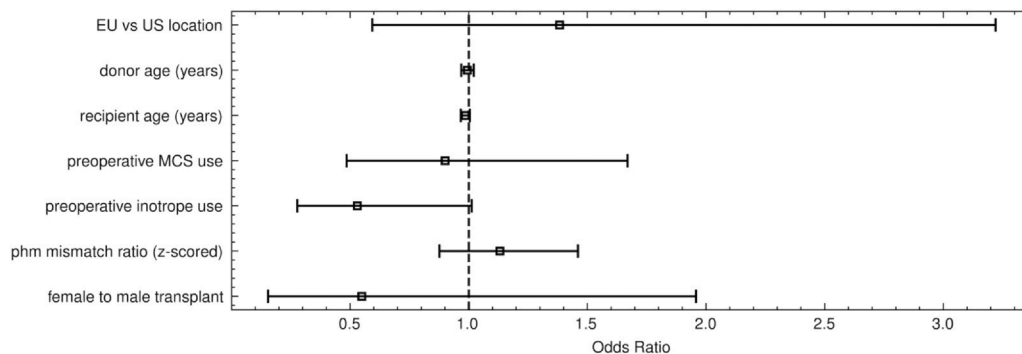


Figure 3 *Forest plot demonstrating relationship between selected predictors and development of severe primary graft dysfunction.* Forest plot demonstrating relationship between selected predictors and development of severe primary graft dysfunction. Phm mismatch ratio - predicted heart mass mismatch ratio. $N = 485$ after accounting for missing data.

Table 3 Recipient Outcomes and Immunological Data

Recipient post-operative outcomes	US	Count number (%)	Europe	Count number (%)	p-value
Survival at 30 days (%)	97.5	281 (100.0%)	95.5	223 (100.0%)	0.23
Survival at 1 year (%)	91.8	274	86.6	214	0.043
Survival at 3 years (%)	79.8	138	82.0	129	0.64
Post-transplant MCS	31 (11%)	281 (100.0%)	40 (17.9%)	223 (100.0%)	0.03
ECMO	26 (83.9%)	281 (100.0%)	39 (97.5%)	223 (100.0%)	
RVAD	5 (16.1%)	281 (100.0%)	1 (2.5%)	223 (100.0%)	
Ventilator hours	24.00 [16.4-53.0]	257 (91.5%)	31.00 [13.5-91.0]	215 (96.4%)	0.482
ICU stay (days)	6.86 [5.0-10.0]	250 (89.0%)	7.00 [4.0-13.8]	218 (97.8%)	0.465
LV ejection fraction at 1 month (%)	58.50 [55.0-65.0]	274 (97.5%)	62.50 [57.5-67.0]	200 (89.7%)	<0.001
LV ejection fraction at 12 months (%)	59.00 [55.0-65.0]	247 (87.9%)	60.00 [55.8-64.0]	184 (82.5%)	0.117
TAPSE at 1 month (mm)	10.00 [1.5-12.2]	250 (89.0%)	11.00 [9.0-14.0]	170 (76.2%)	<0.001
TAPSE at 1 year (mm)	11.00 [1.6-15.0]	237 (84.3%)	14.00 [11.2-17.0]	170 (76.2%)	<0.001
Proportion of patients with eGFR > 60 ml/min/1.73 m ² at time of transplant*	176 (63.5%)	277 (98.6%)	129 (58.9%)	219 (98.2%)	0.31
Proportion of patients with eGFR > 60 ml/min/1.73 m ² at 1 year post transplant*	24.91%	242 (86.1%)	40.81%	192 (86.1%)	<0.001
<i>Immunological data</i>					
Total number of acute cellular rejection requiring treatment in first year	90 (32%)	281 (100.0%)	50 (22.4%)	223 (100.0%)	
2R ACR in first year	87		47		
3R ACR rejection in first year	3		3		
Number of patients who had an episode of ACR requiring treatment in the first year (%)	61 (21.7%)	281 (100.0%)	39 (17.5%)	223 (100.0%)	0.26
ACR events per patient in the first year	0.32		0.22		1.0
Percentage of patients with 2 or more episodes of ACR	6.41		3.14		0.10
Total number of biopsies/cf-DNA in year 1 - according to routine surveillance schedule	2250		1815		
Average number of surveillance tests in year 1 per patient*	8.01		8.14		0.32
Rejections per surveillance test, rate in first year of transplant according to routine schedule*	0.04		0.03		0.03
Proportion of patients with at least 1 rejection episode in the first year per surveillance test	2.71		2.15		1
Number of patients with panel reactive antibody/calculated reaction frequency > 80% (%)	3.20%	9.0 (1.8%)	1.79%	4.0 (0.8%)	0.403
Number of patients with de novo donor specific anti-HLA antibodies post-transplant at any point (%)	51 (19%)	274 (97.5%)	17 (8%)	209 (93.7%)	<0.001
% of recipients who were CMV positive at the time of transplant	106 (38.3%)	277 (98.6%)	73 (33.2%)	220 (98.7%)	0.26
<i>Immunosuppressant use</i>					
Number of patients who received induction therapy (%)	173 (61.6%)	281 (100.0%)	195 (87.4%)	223 (100.0%)	<0.001
ATG (%)	19 (11.0%)		112 (57.4%)		
Basiliximab (%)	154 (89.0%)		34 (17.4%)		
ATG + Basiliximab (%)	0		49 (25.1%)		
Ever on a calcineurin inhibitor (%)	278 (98.9%)	281 (100.0%)	216 (98.6%)	219 (98.2%)	1
Ever on a mycophenolate mofetil (%)	279 (99.3%)	281 (100.0%)	163 (73.1%)	223 (100.0%)	<0.001
Ever on an mTOR inhibitor (%)	80 (28.5%)	281 (100.0%)	50 (23.4%)	214 (96.0%)	0.22
Ever on steroids (%)	281 (100.0%)	281 (100.0%)	222 (99.6%)*	223 (100.0%)	0.44

Recipient outcomes and immunological data.

*The predominant surveillance screening test was endomyocardial biopsy. 23 of the 504 cases were routinely screened with cf-DNA throughout the first year.

**There was one intraoperative death in this group - hence why not all patients received steroids.

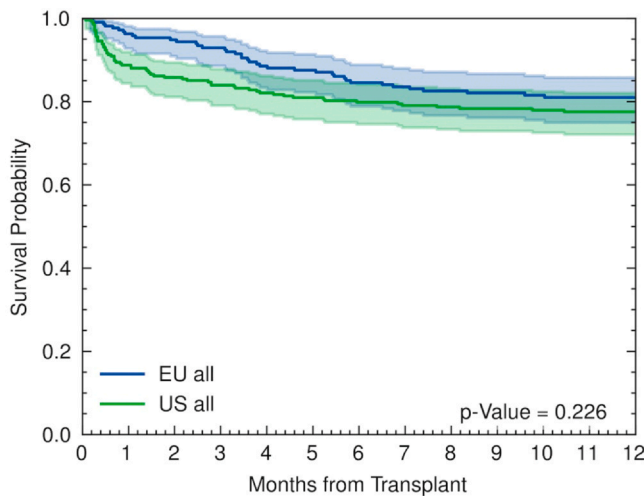


Figure 4 *Kaplan Meier curve for rejection free survival.* Rejection-free survival after HT in the first-year post-transplant, including the table with numbers at risk. The Log-rank statistic: 11.848, p -value = 0.22.

Discussion

This is the first large-scale international multicenter study comparing outcomes after DCD HT between centers in Europe and the US.

Survival

There was significantly higher survival in the US cohort at 1-year post-transplant. This difference in survival was no longer present at 3 years post-transplant, but this comparison is limited by relatively small numbers in the US group at this time point. This difference in survival seems to have been due predominantly to improved 1-year survival in the US DPP group compared to the European DPP group. The mixed-effect (Supplementary Figure 3) model demonstrated that region was a significant predictor in the taNRP

subgroup; however, this difference was likely secondary to the relatively small numbers in this group and the number of variables in the model. The higher survival in the US DPP group may be related to the lower incidence of severe PGD in this group; however, a causal link between severe PGD and worse survival has yet to be definitively demonstrated in DCD HT. Alternatively, the superior survival in the US group may be driven by the higher proportion of male donors or by a significantly younger median recipient age.

These findings are similar to those observed in DBD HT, where there is superior short-term survival in the US, but with European recipients having a greater median survival.²⁸ In spite of 1-year survival differences, our data provide further support that DCD HT has similar overall survival across centers in the US and Europe. This may enable use of older DCD donors with greater confidence in the US, especially if hearts from these donors are obtained via taNRP. A previous analysis of this data demonstrated no difference in overall survival between DPP and taNRP groups.¹⁹

Severe primary graft dysfunction

There was a higher incidence of severe PGD in the European group. This contrasts with DBD HT, where the incidence of severe PGD is similar across the US and Europe. Pre-transplant MCS is recognized as a risk factor for the development of PGD.²⁹ However, in our study, the European centers had fewer patients supported on MCS pre-transplant. A possible explanation for the higher incidence of severe PGD may be the older age of donors in the European cohort. Additionally, there was a higher proportion of taNRP cases in the US group, and higher utilization of taNRP may have contributed to the lower rates of severe PGD.

These data demonstrate that worse outcomes with respect to PGD and short-term survival are only associated with DPP use in Europe, but not taNRP. It may be that taNRP enables safer recovery of older hearts by avoiding

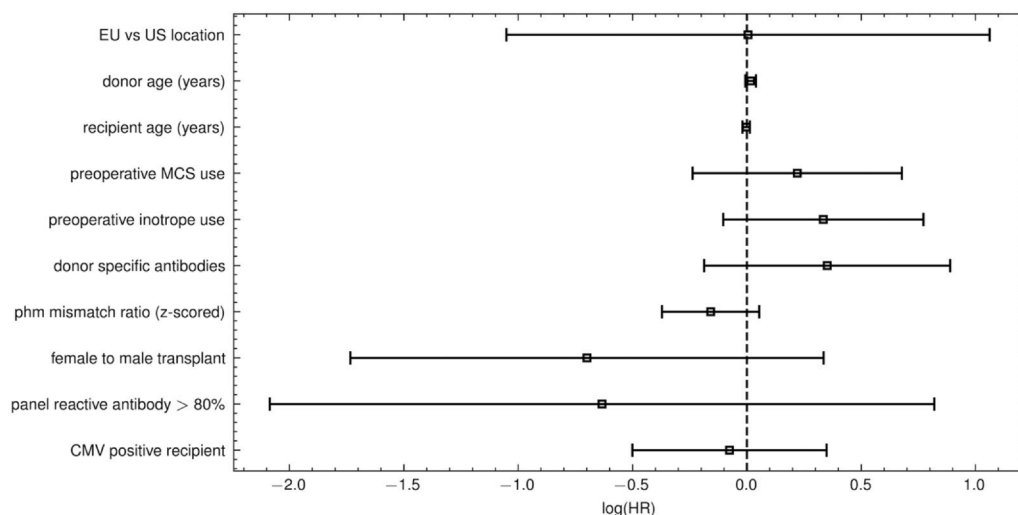


Figure 5 *Cox mixed effects model for the development of acute cellular rejection in the first year post-operatively.* Forest plot demonstrating the relationship, between selected predictors and the development of acute cellular rejection. Phm mismatch ratio - predicted heart mass mismatch ratio. $N = 416$, after accounting for missing data.

the deleterious effects of ex situ machine perfusion, whilst younger hearts are more able to tolerate this insult.^{30,31} Data from DBD transplantation has demonstrated that hearts from younger donors are able to better tolerate prolonged cold storage times, thus supporting this notion of increased resilience to insult seen in younger donor hearts.³² Alternatively, it may be that taNRP allows better assessment of heart function before recovery, thereby enabling safer retrieval of older donor hearts.

Rates of ACR and immunosuppressant use

Rejection-free survival was similar between both groups, as seen in Figure 4. This was despite significant differences in immunosuppression. There was lower utilization of antibody induction therapy in US recipients and a preference for Basiliximab, whilst European centers tended to use either ATG or both ATG and Basiliximab. These data are limited by relatively small numbers in each group, but they suggest that the use of induction therapy, and the subtype used, have no significant effect on rejection-free survival in the first-year post-transplant. A recent meta-analysis found little evidence of an association between induction therapy and greater survival.³³

Donor demographics and rates of organ utilization

US donors were typically younger, and a higher proportion were male. This may reflect the higher incidence of trauma seen in this group as the cause of death. Additionally, in the US, a greater number of lungs, livers, and kidneys were transplanted per donor. This may be due in part to the younger donor median age, with younger donors being more likely to be multi-visceral organ donors.³⁴ Moreover, the US cohort had a higher use of taNRP, a technique associated with greater utilization of abdominal organs.^{35,36} Differences in organ utilization may also be due in part to policy and necessary infrastructure for organ donation and transplantation. However, as with DBD transplantation, it appears that there is potential for safe use of older DCD donor hearts in the US, which in turn may further expand the donor pool and increase the number of transplants performed.

Intraoperative data

There were important differences in intraoperative parameters between the US and European centers. US centers had a significantly shorter FWIT on average. It is difficult to comment on the clinical significance of the additional 4 min of FWIT seen in the European cohort. It may reflect the difference in surgical techniques and stand-off times between centers in the US and Europe. There have been documented cases of stand-off periods < 5 min in the US.³⁷ Moreover, taNRP recovery in the US involves clamping the aortic arch vessels, whereas in the UK and Spain the aortic arch vessels are clamped, divided, and opened up to the atmosphere, or negative pressure is applied to the cephalad ends.³⁸ This increases the duration of time before

reperfusion in-situ and subsequently increases the FWIT; however, it may reduce the risk of restarting cerebral perfusion.^{39,40} The difference in FCIT may be explained by the greater degree of instrumentation and preparation of donor hearts on the bench in the US compared to Europe.

Recipient demographics

US recipients were more likely to be diabetic pre-transplant.⁴¹ Additionally, US recipients were almost twice as likely to have been supported on MCS pre-transplant, with the overwhelming majority on left ventricular assist devices. This may be due to a more aggressive MCS implantation practice in the US compared to European countries. Nonetheless, these data may suggest that it is safe and feasible to use DCD hearts in recipients with these established co-morbidities. Whether there is any difference in outcomes from high-risk DBD and DCD recipients post-operatively is not known. Future work should focus on establishing whether there are advantages of one donor type over another in this group.

Limitations

This paper is limited by its retrospective and observational nature, with its inherent selection bias. The observed differences between the US and Europe may simply reflect differences between the centers participating in the study. Only 7 centers from the US were included in this study, but the data were comparable to previous UNOS data analyses.⁴² There is a need to collect further granular intraoperative data to better understand the differences in operative techniques as well as the impact of ex-situ heart perfusion on the outcomes of DCD HT. Use of MCS after HT was used as an indicator of severe PGD; we acknowledge that mild and moderate PGD were not measured, and we suspect that a proportion of severe PGD may represent secondary graft dysfunction. Further to this, no data on intra-aortic balloon pump use pre-operatively or post-operatively was collected. We understand that each center will have different thresholds for starting MCS in the post-operative period. This study did not collect data on implant times, which represents an additional period of warm ischemia. There was significant heterogeneity in the number of cases performed between centers. As DCD becomes more widely adopted and programs have been running for longer periods, this will become less of an issue.

Conclusion

This study further confirms the safety and efficacy of DCD HT across centers in the US and Europe, despite important differences in donor and recipient demographics and clinical outcomes. Continued collection of international registry data will be imperative to optimize donor heart utilization and recipient outcomes as DCD HT becomes even more widely adopted.

Disclosure statement

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Appendix A. Supplementary data

Supplementary data associated with this article can be found in the online version at [doi:10.1016/j.healun.2026.04.007](https://doi.org/10.1016/j.healun.2026.04.007).

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