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Normothermic Regional Perfusion Can Improve Both Utilization and Outcomes in DCD Liver, Kidney, and Pancreas Transplantation

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Background. Normothermic regional perfusion (NRP) has gained widespread adoption in multiple European countries. The aim of this study was to examine the influence of thoracoabdominal-NRP (TA-NRP) on the utilization and outcomes of liver, kidney, and pancreas transplantation in the United States. **Methods.** Using the US national registry data between 2020 and 2021, donation after circulatory death (DCD) donors were separated into 2 groups: DCD with TA-NRP and without TA-NRP. There were 5234 DCD donors; among them 34 donors were with TA-NRP. After 1:4 propensity score matching, the utilization rates were compared between DCD with and without TA-NRP. **Results.** Although the utilization rates of kidney and pancreas were comparable ($P=0.71$ and $P=0.06$, 94.1% versus 95.6% and 8.8% versus 2.2%, respectively), that of liver in DCD with TA-NRP was significantly higher ($P<0.001$; 70.6% versus 39.0%). Among 24 liver transplantations, 62 kidney transplantations, and 3 pancreas transplantations from DCD with TA-NRP, there were 2 liver grafts and 1 kidney graft that failed within 1 y after transplantation. **Conclusions.** TA-NRP in the United States significantly increased the utilization rate of abdominal organs from DCD donors with comparable outcomes after transplantation. Increasing use of NRP may expand the donor pool without compromising transplant outcomes.

(Transplantation Direct 2023;9: e1450; doi: 10.1097/TXD.0000000000001450.)

The number of donation after circulatory death (DCD) donors has steadily increased during the decade, with a

recent report demonstrating they account for 25% of deceased donation in the United States.[1] Because of a gap between the supply and demand in liver (LT), kidney (KT), and pancreas transplantation (PT), aggressive utilization of marginal donors is required including DCD donors.[2] However, the utilization of potential DCD donors for transplantation has remained low. The 2020 annual report of the US Organ Procurement and Transplantation Network (OPTN) showed that although 26.2% of transplanted kidneys were from DCD donors,[3] <10% of transplanted livers or pancreas were from DCD donors.[4,5]

Previous studies reported that transplantation from DCD donors faces increased risks of complications linked to the detrimental effects of donor warm ischemia time (dWIT): primary nonfunction (PNF) and biliary complications in LT, PNF and delayed graft function (DGF) in KT, and thrombosis in PT.[6,7] Total dWIT is the time interval between withdrawal of life support and the start of cold perfusion in the aorta. To minimize the duration of organ warm ischemia, rapid recovery technique has been widely used for DCD organ procurement. However, this technique is associated with increased risk of surgical injury because of the haste in procuring the organs.[7,8] The unpredictable consequences of the dWIT, together with increased risk of graft injury during organ procurement, have resulted in a reluctance to use grafts from DCD donors.[7] Over the last decade, normothermic regional perfusion (NRP) has been introduced and widely adopted in select European countries.[7,9-12] NRP provides in situ perfusion and oxygenation of

the potentially transplantable organs following death declaration.[6] In situ perfusion arrests the ischemic damage of the dWIT and allows organs to recover before cold organ flush is performed during organ procurement.[9]

Several studies of NRP thus far demonstrated superior outcomes and lower complications, including biliary complications in DCD LT across European countries.[9-11,13] Similarly, favorable outcomes in KT and PT from DCD donors with NRP have been reported.[7,12,13] Following these results, NRP for DCD donors has become the standard of care or mandatory in some countries.[6,12,14,15] Because there have been significant differences in the DCD practice between the United States and European countries,[16,17] further investigation into the impact of NRP in the US population is warranted.

During NRP, perfusion can be limited to the abdomen (A-NRP) or both abdomen and chest (thoracoabdominal-NRP [TA-NRP]).[6] TA-NRP was started in 2020 in the United States.[18,19] In TA-NRP for DCD procurement, a sternotomy and laparotomy are performed, the innominate, left common carotid, and left subclavian arteries are occluded to prevent reperfusion of the brain, the right atrium and aorta are cannulated, and normothermic perfusion is initiated.[18,19] Recently, Sellers et al[20] reported favorable outcomes after LT of 13 patients using TA-NRP for DCD.[20] However, there has not been an evaluation of utilization rate and outcomes in the United States between DCD transplants with and without TA-NRP. The aim of this study was to use the US national registry data to examine the influence of TA-NRP on the utilization of liver, kidney, and pancreas grafts. We also evaluate the prognostic impact of TA-NRP compared with DCD transplant without TA-NRP. Thereby, the results of this study may guide the indication and the application of NRP in the United States.

MATERIALS AND METHODS

We reviewed the United Network for Organ Sharing (UNOS) Standard Transplant Analysis and Research data on adult donors who underwent organ procurement from January 1, 2020, to June 30, 2021. The start date of our study corresponds to the first report of TA-NRP in the United States.[18,19] Donors were categorized into DBD, DCD with TA-NRP, and DCD without TA-NRP. Accuracy of the identified cases was verified by cross reference with published clinical trial protocols and published results. Components of dWIT were also reviewed from the [Deceased_Donor_DCD_Measures] file to ensure that cases were consistent with TA-NRP.[21] The utilization rate, defined as the proportion from all deceased donors to the transplanted grafts, was evaluated for liver, kidney, and pancreas.[22] Among used grafts, outcomes of LT, KT, and PT recipients were further evaluated. This study was exempted from institutional review board approval because the study involves de-identified publicly available secondary data sets. Informed consent was waived because the data obtained were completely de-identified before their transmission to the investigators.

To evaluate the impact of TA-NRP on organ yield, an observed to expected ratio or "O:E ratio" was computed.[23] The expected yield values were calculated using the risk-adjusted expected yield model released by the Scientific Registry of Transplant Recipients in January 2022.[24] The analysis determines whether the observed organ yields of TA-NRP donors with intent to transplant were statistically different from the expected yields for each organ. The analysis divides the observed yield by the expected yield, where a ratio value of 1 would imply that the expected yield and observed yield are equal.

Statistical analysis was performed using SAS 9.4 (SAS Institute, Cary, NC), and statistical significance was set at a P value of <0.05. Data were summarized using median (interquartile range [IQR]) for continuous variables and number and percentage for categorical variables). Categorical variables were analyzed using the chi-square test. Analysis of variance was used to analyze differences among different donor types. Continuous variables between the 2 groups were compared using the 2-tailed Student t test or the 2-tailed Mann-Whitney U test according to distribution. Multivariable logistic regression model was performed to identify characteristics associated with graft nonutilization. The following donor variables were used to adjust the odds ratio (OR) and 95% confidence interval (95% CI): age, body mass index (BMI), history of diabetes, history of hypertension. To validate the impact of TA-NRP on liver graft utilization, we used a propensity score matching model. A 1:4 propensity match among donors with and without TA-NRP was performed for the following variables: gender, age, BMI, history of diabetes, ethnicity, and cause of death. We estimated the propensity score using a multivariable logistic regression model in which all variables listed earlier were included. Propensity score matching was performed using a caliper width of 0.20. In the matched cohort, graft utilization rates were analyzed. Graft survival curves were generated using the Kaplan-Meier method and compared by the log-rank test. Individual models of graft survival were created with survival truncated and right censored at 1 y.

The data reported here have been supplied by the UNOS as the contractor for OPTN. The interpretation and reporting of these data are the responsibility of the authors and in no way should be seen as an official policy of or interpretation by the OPTN or the US Government.

RESULTS

Donor Utilization

There were 19 503 deceased donors in the United States within the study period (**Figure S1, SDC**, http://links.lww.com/TXD/A504). Those donors were DBD in 14 269 (73.2%) and DCD in 5234 (26.8%). A total of 34 DCD donors used TA-NRP (0.6%), with TA-NRP activity increasing rapidly during this period (Figure 1). Table 1 summarizes the pertinent donor demographics according to type of donors (DBD versus DCD without TA-NRP versus DCD with TA-NRP). DCD with TA-NRP donors were younger ($P < 0.001$; 27.5 versus 41 y in DBD and 46 y in DCD without TA-NRP) and had lower BMI ($P < 0.001$; 26.9 versus 27.4 kg/cm² in DBD and 28.3 kg/cm² in DCD without TA-NRP), with decreased rates of donor diabetes ($P < 0.001$) or hypertension ($P < 0.001$). Trauma as cause of death was more prevalent in DCD with TA-NRP donors compared with DBD or DCD without TA-NRP ($P < 0.001$; 50.0% versus 21.3% versus 25.1%, respectively).

Figure 2A–C demonstrates the utilization rates of liver, kidney, and pancreas based on donor types. The utilization rates of liver and pancreas in DCD with TA-NRP donors
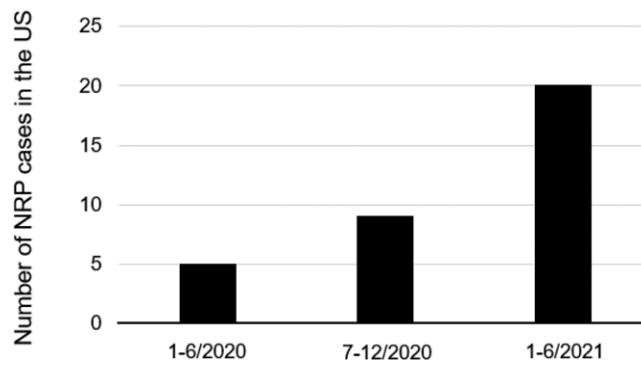
FIGURE 1. TA-NRP activity in the United States has been increasing since 2020. TA-NRP, thoracoabdominal-normothermic regional perfusion.

TABLE 1.

Potential donor demographics

Variables	DBD (n = 14 269)	DCD without TA-NRP (n = 5200)	DCD with NRP (n = 34)	P
Age (y)	41 (29–55)	46 (33–56)	27.5 (21–34)	<0.001
Gender F/M	5680/8589	1769/3431	5/29	<0.001
	(39.8%/60.2%)	(34.0%/66.0%)	(14.7%/85.3%)	
COD (%)	6503/3867/3578	2750/1056/1109	14/2/17	<0.001
Anoxia/stroke/trauma	(45.6/27.1/25.1)	(52.9/20.3/21.3)	(41.2/5.6/50.0)	
BMI (kg/cm²)	27.4 (23.5–32.4)	28.3 (24.0–33.7)	26.9 (24.5–29.7)	<0.001
DM	1974 (13.8%)	633 (12.2%)	0	<0.001
HTN	5157 (36.1%)	2029 (39.0%)	4 (11.8%)	<0.001
AST (U/L)	43 (24–93)	56 (33–100)	46.5 (25–71)	<0.001
ALT (U/L)	40 (22–84)	42 (23–86)	38 (22–66)	0.003
T-Bil (mg/dL)	0.6 (0.4–1.1)	0.6 (0.4–0.9)	0.7 (0.4–1.2)	<0.001
Creatinine (mg/dL)	1.1 (0.8–2.1)	0.8 (0.6–1.3)	0.7 (0.6–1.0)	<0.001

Values are presented as the n (%) or median (IQR).
ALT, alanine aminotransferase; AST, aspartate transaminase; BMI, body mass index; COD, cause of death; DBD, donation after brain death; DCD, donation after circulatory death; DM, diabetes mellitus; IQR, interquartile range; NRP, normothermic regional perfusion; TA, thoracoabdominal; T-Bil, total bilirubin.

were significantly higher compared with that in DCD without TA-NRP donors and similar to that of DBD ($P < 0.001$ in both; 70.6% versus 24.4% versus 80.3% and 8.8% versus 0.8% versus 10.2%, respectively). The utilization rate of kidney was also higher in DCD with TA-NRP donors ($P = 0.06$, 78.7% in DBD, 78.2% in DCD without TA-NRP, and 94.1% in DCD with TA-NRP). We performed propensity score matching to validate the impact of TA-NRP on the utilization rates. After propensity score matching, 136 donors were selected DCD without TA-NRP (**Table S1, SDC,** http://links.lww.com/TXD/A504). The utilization rate of liver grafts in the matched cohort were also significantly higher in DCD with TA-NRP compared with that of DCD without TA-NRP (**Figure S2A, SDC,** http://links.lww.com/TXD/A504; $P < 0.001$; 70.6% versus 34.6%). The utilization rate of kidney and pancreas grafts in the matched cohort did not reach statistical significance (**Figure S2B and C, SDC,** http://links.lww.com/TXD/A504; $P = 0.71$ and $P = 0.06$; 94.1% versus 95.6% and 8.8% versus 2.2%, respectively).

Multivariable regression (Tables 2–4) identified that DCD with TA-NRP was an independent protective factor for nonutilization of liver grafts (OR 0.18, 95% CI, 0.10-0.39; $P < 0.001$) and pancreas grafts (OR 0.14; 95% CI, 0.04-0.47; $P = 0.002$): The odds of LT and PT being undertaken were approximately 5.6 times and 7.1 times higher for donors who underwent NRP than for those who did not, respectively. DCD with TA-NRP was not found as an independent predictor for nonutilization of kidney grafts (OR 0.80; 95% CI, 0.19-3.43;

$P = 0.76$). The O:E ratios for liver (O:E 2.39; 95% CI, 2.04-2.75) and kidney (O:E 1.20; 95% CI, 1.05-1.35) was >1, implying that the observed yield was above expected yield. The O:E ratio for the pancreas yield was also >1 (O:E 37.97; 95% CI, –5.72 to 81.67) but did not reach statistical significance.

Analysis of Liver Donors and Recipients

Among 5234 DCD donors, 1291 DCD livers were transplanted, among whom 24 livers (1.9%), were from DCD donors with TA-NRP. Donor and recipient characteristics of DCD LT are outlined in Table 5. DCD with TA-NRP donors were younger ($P < 0.001$; 26 versus 37 y). Recipient demographics were comparable in recipient age ($P = 0.86$; 59.5 versus 59 y) and laboratory MELD score ($P = 0.88$; 18 versus 19).

Survival analysis was performed to determine graft survival during a median follow-up time of 359 d (IQR, 306–382) and 366 d (348–544) in DCD with and without TA-NRP, respectively ($P = 0.19$). Kaplan-Meier survival curves in Figure 3A demonstrated comparable graft survival at 1 y after LT between DCD with and without TA-NRP ($P = 0.64$; 91.3% versus 88.5%, respectively). After propensity score matching, liver graft survival was compared in the matched cohort demonstrating comparable graft survival. ($P = 0.76$; 91.3% versus 93.8%, respectively). Causes of liver graft loss are summarized in Table 6. There were 2 cases of liver graft loss during the study period out of 24 DCD LTs with TA-NRP. Causes of graft loss were heart failure at 6 mo and malignancy at 9 mo after DCD LT.

A

B

C
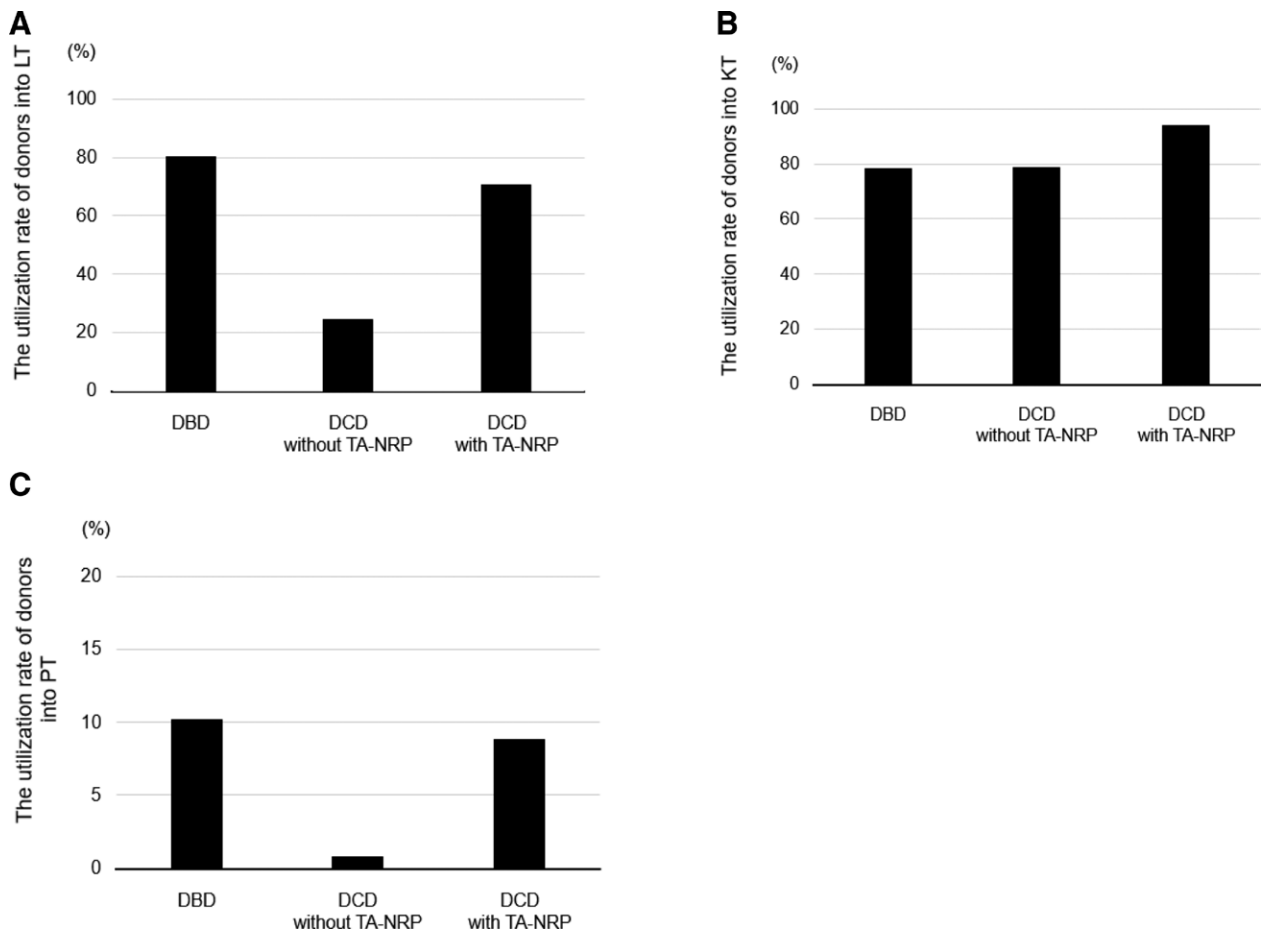
FIGURE 2. Utilization rates of livers (A), kidneys (B), and pancreas (C) were compared between DCD with and without TA-NRP. The utilization rate of liver and pancreas in DCD with TA-NRP donors was significantly higher compared with that in DCD without TA-NRP donors and similar to that of DBD ($P < 0.001$ in both; 70.6% vs 24.4% vs 80.3% and 8.8% vs 0.8% vs 10.2%, respectively). The utilization rate of kidney was also higher in DCD with TA-NRP donors ($P = 0.06$, 78.7% in DBD, 78.2% in DCD without TA-NRP, and 94.1% in DCD with TA-NRP). DBD, donation after brain death; DCD, donation after circulatory death; KT, kidney transplantation; LT, liver transplantation; PT, pancreas transplantation; TA-NRP, thoracoabdominal-normothermic regional perfusion.

TABLE 2.

Multivariate logistic regression models for nonutilization of liver grafts

Variables	OR	95% CI	Coefficient	P
Type of donor (ref: DCD standard)				
DCD NRP	0.18	0.10-0.39	−1.69	<0.001
DBD	0.08	0.07-0.08	−2.60	<0.001
Donor age (per year)	1.02	1.01-1.02	0.02	<0.001
Donor BMI (per kg/cm^2)	1.03	1.03-1.04	0.03	<0.001
History of DM	1.28	1.15-1.42	0.25	<0.001
History of HTN	1.21	1.11-1.31	0.19	<0.001

BMI, body mass index; CI, confidence interval; DBD, donation after brain death; DCD, donation after circulatory death; DM, diabetes mellitus; HTN, hypertension; NRP, normothermic regional perfusion; OR, odds ratio.

Analysis of Kidney Donors and Recipients

Among 5234 DCD donors, 4126 donors (7497 kidneys) were used, among whom 32 donors (62 kidneys) were with TA-NRP. Donor and recipient characteristics of DCD KT are outlined in Table 7. DCD with TA-NRP donors were younger ($P < 0.001$; 27 versus 42 y). Recipient demographics in DCD with TA-NRP demonstrated significantly younger recipient age ($P < 0.001$; 44 versus 57 y) and shorter CIT ($P = 0.004$; 16.5 versus 19.5 h). Post-KT creatinine at 1 y was significantly lower ($P < 0.001$; 1.2 versus 1.4 mg/dL).

Survival analysis was performed to determine graft survival during a median follow-up time of 363 d (IQR, 344–371) and 365 d (346–411) in DCD with and without TA-NRP, respectively ($P = 0.03$). Kaplan-Meier survival curves in Figure 3B demonstrated superior graft survival at 1 y after DCD KT with TA-NRP ($P = 0.049$; 98.4% versus 90.6%, respectively). After propensity score matching, kidney graft survival was compared in the matched cohort demonstrating superior graft survival after DCD KT with TA-NRP ($P = 0.049$; 98.4% versus 90.0%, respectively). There were 4 cases of kidney graft

TABLE 3.

Multivariate logistic regression models for nonutilization of kidney grafts

Variables	OR	95% CI	Coefficient	P
Type of donor (ref: DCD standard)				
DCD NRP	0.80	0.19-3.43	−0.23	0.76
DBD	1.04	0.96-1.13	0.04	0.37
Donor age (per year)	1.06	1.05-1.06	0.05	<0.001
Donor BMI (per kg/cm^2)	0.99	0.98-0.99	−0.01	<0.001
History of DM	2.74	2.49-3.03	1.01	<0.001
History of HTN	2.29	2.10-2.50	0.83	<0.001

BMI, body mass index; CI, confidence interval; DBD, donation after brain death; DCD, donation after circulatory death; DM, diabetes mellitus; HTN, hypertension; NRP, normothermic regional perfusion; OR, odds ratio.

TABLE 4.

Multivariate logistic regression models for nonutilization of pancreas grafts

Variables	OR	95% CI	Coefficient	P
Type of donor (ref: DCD standard)				
DCD NRP	0.14	0.04-0.47	−2.00	0.002
DBD	0.07	0.05-0.10	−2.66	<0.001
Donor age (per year)	1.06	1.05-1.06	0.05	<0.001
Donor BMI (per kg/cm^2)	1.07	1.06-1.08	0.07	<0.001
History of HTN	4.46	3.39-5.88	1.50	<0.001

BMI, body mass index; CI, confidence interval; DBD, donation after brain death; DCD, donation after circulatory death; HTN, hypertension; NRP, normothermic regional perfusion; OR, odds ratio.

TABLE 5.

DCD liver donor and recipient demographics

Variables	DCD LT without TA-NRP (n = 1267)	DCD LT with NRP (n = 24)	P
Donor			
Age (y)	37 (28–48)	26 (20.5–29.5)	<0.001
Gender F/M (%)	406/861 (32.0/68.0)	4/20 (16.7/83.3)	0.11
COD (%)	689/208/326	10/1/12	0.04
Anoxia/stroke/trauma	(54.4/16.4/25.7)	(41.7/4.2/50.0)	
BMI (kg/cm^2)	26.5 (23.2–31.1)	26.4 (24.2–29.2)	0.87
AST (U/L)	51 (32–83)	46 (22.5–70.5)	0.06
ALT (U/L)	40 (23–75)	36.5 (23.5–70)	0.20
T-Bil (mg/dL)	0.5 (0.4–0.8)	0.7 (0.4–1.1)	0.21
Recipient			
Age (y)	59 (52–66)	59.5 (54–63)	0.86
BMI (kg/cm^2)	28.8 (25.1–33.2)	31.2 (27.9–35.5)	0.04
Laboratory MELD score	19 (14–24)	18 (16–23.5)	0.88
Re-LT	6 (0.5%)	0	0.74
HCC	254 (20.1%)	7 (29.2%)	0.27
Waitlist time	110 (25–269)	234 (53–559.5)	0.22
SLK	115 (9.1%)	4 (16.7%)	0.20
CIT (h)	5.3 (4.5–6.3)	4.8 (3.7–5.8)	0.13

Values are presented as the n (%) or median (IQR).
ALT, alanine aminotransferase; AST, aspartate transaminase; BMI, body mass index; CIT, cold ischemia time; COD, cause of death; DCD, donation after circulatory death; F/M, female/male; HCC, hepatocellular carcinoma; IQR, interquartile range; LT, liver transplantation; MELD, Model for End-stage Liver Disease; NRP, normothermic regional perfusion; SLK, simultaneous liver-kidney; T-Bil, total bilirubin; TA-NRP, thoracoabdominal-NRP.

loss during study period out of 32 DCD KTs with TA-NRP. One graft loss was because of acute rejection at 15 mo without patient mortality. The other 3 were mortality with functioning grafts: unspecified reason at 19 d, infection at 12 mo, and hemorrhage at 16 mo.

Analysis of Pancreas Donors and Recipients

Among 5234 DCD donors, 44 pancreases were transplanted, among whom 3 pancreases (0.7%) were from DCD donors with TA-NRP. Donor and recipient characteristics of DCD PT are outlined in Table 8. There were no significant differences in donor age (P = 0.76; 21 versus 22 y), donor BMI (P = 0.81; 21.6 versus 23.2 kg/cm^2, respectively), or recipient age (P = 0.59; 40 versus 45 y) between DCD with and without TA-NRP.

Survival analysis was performed to determine graft survival during a median follow-up time of 370 d (IQR, 369–379) and 364 d (341–385) in DCD with and without TA-NRP, respectively (P = 0.44). Kaplan-Meier survival curves in Figure 3C demonstrated comparable graft survival at 1 y after PT between DCD with and without TA-NRP (P = 0.58; 100.0% versus 90.2%, respectively). After propensity score matching, pancreas graft survival was compared in the matched cohort demonstrating comparable graft survival (P = 0.62; 100% versus 91.7%, respectively). There was 1 graft loss during study period out of 3 DCD PTs with TA-NRP. The cause of graft loss was infection at 12 mo with patient mortality.

DISCUSSION

NRP in European countries has become widely adopted because of its success with increasing graft utilization and improving outcomes after DCD transplantation.[7,9-12] Because there have been significant differences in DCD transplant practice between the United States and European countries,[16,17] the impact of NRP in the US cohort needs to be evaluated. This study using UNOS data found that TA-NRP increased the utilization rate of liver by >2 times (from 24.4% to 70.6%) and pancreas by 10 times (from 0.8% to 8.8%). Although there has been a significant improvement in the outcomes from DCD donors, the utilization rate has not increased in the United States because of the highly subjective assessment of organ quality and concerns about organ function.[21] Through increasing adoption of NRP practice in the United States, the donor pool may be expanded by increasing the organ utilization for transplantation. Interestingly, previous studies from European countries showed that NRP improved outcomes after DCD transplantation although NRP has been applied to high-risk donors and older donors.[10,11,25] Contrary to the practice in European countries, DCD donors within the TA-NRP group in the United States were more

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B

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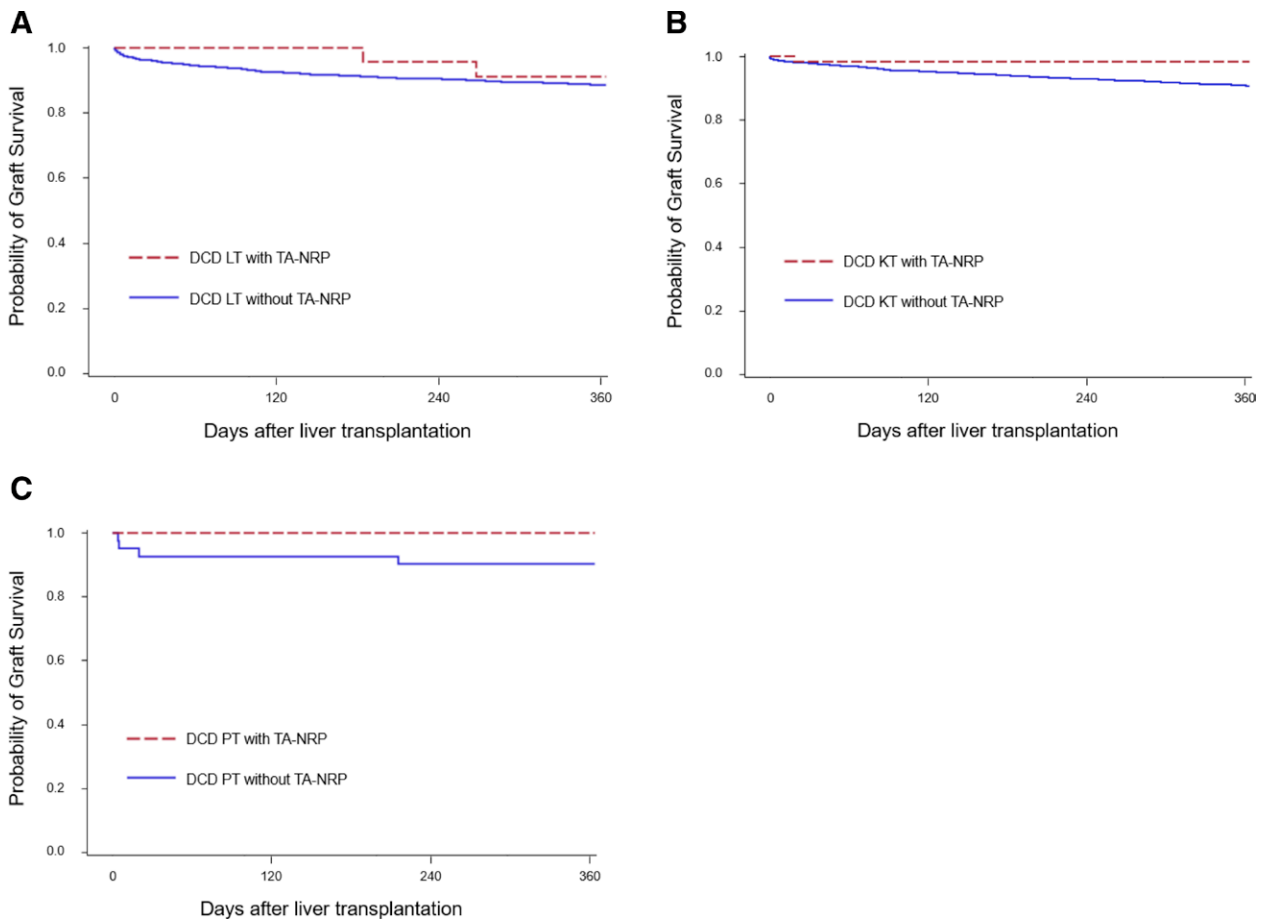
FIGURE 3. Kaplan-Meier curves illustrating 1-y graft survival after DCD LT (A), DCD KT (B), and DCD PT (C). There were comparable graft survival at 1 y between DCD with and without TA-NRP after LT ($P=0.64$; 91.3% vs 88.5%, respectively) and PT ($P=0.58$; 100.0% vs 90.2%, respectively). Graft survival after DCD KT with TA-NRP was superior to that without TA-NRP ($P=0.049$; 98.4% vs 90.6%, respectively). DCD, donation after circulatory death; KT, kidney transplantation; LT, liver transplantation; PT, pancreas transplantation; TA-NRP, thoracoabdominal-normothermic regional perfusion.

often younger donors. Given that graft survivals after transplantation in DCD with TA-NRP were comparable with that in DCD without TA-NRP in our study, application of NRP with older DCD donors can be considered.

DCD donation has had a considerable impact on KT with utilization rates comparable with DBD donation and acceptable outcomes.[2,6] In contrast to DCD kidney, only a minority of DCD liver and pancreas grafts are used in the United States. DCD LT and PT contributed to only 9.9%[5] and <5%[4] of all deceased donor transplants, respectively. Broader utilization of DCD liver and pancreas grafts has been hampered by limited assessment of graft viability.[12] However, NRP has the ability to test graft viability and function during the period of NRP.[9] Our data showed the liver and pancreas utilization rates in DCD with TA-NRP were significantly higher compared with those in DCD without TA-NRP (70.7% versus 24.4 and 8.8% versus 0.8%, respectively). On multivariable analysis, TA-NRP was identified as an independent predictor in liver and pancreas graft utilization. Those results encourage that TA-NRP increases organ yield in DCD donors through graft function assessment and mitigating the reluctance to use DCD grafts. In contrast to liver and pancreas grafts, kidney graft utilization did not show statistical difference between DCD with and without TA-NRP. Less impact of TA-NRP on kidney utilization may be because of the widespread machine

perfusion for the preservation of kidney. Machine perfusion allows for organ function assessment and permits decision making for transplantation.[7,26] Therefore, TA-NRP may impact less significantly on DCD kidney utilization. Although cost estimates for TA-NRP suggest an additional $4000 needed for equipment and personnel, when compared with machine perfusion of the heart (~$40 000 per heart),[27] the additional cost may not be prohibitive.[28] Furthermore, NRP restores oxygenated blood flow to multiple organs,[25] contributing to the increase in organ yield from DCD donors. Given simultaneous treatment of multiple organs of TA-NRP leading to a significant impact on overall graft yield, the broader application of TA-NRP may represent a strong solution for organ shortage.

The Centers for Medicare and Medicaid Services (CMS) conducts surveys of Organ Procurement Organizations (OPOs) and recertifies them every 4 y based on their practice. Previously, OPO practice was evaluated by the number of organ procurement procedures divided by the number of eligible deaths and the definitions of an "eligible death" for donation excluded DCD donors,[1] creating disincentives to OPOs to explore donation from such patients.[29,30] Correspondingly, DCD donors were underused and there were significant variations in the utilization of DCD donors across the country.[29,30] Recently, CMS issued a final rule to maximize the donor pool

TABLE 7.
DCD kidney donor and recipient demographics

Variables	DCD KT without TA-NRP (n = 7497)	DCD KT with NRP (n = 62)	P
Donor			
Age (y)	42 (31–52)	27 (21–32)	<0.001
Gender F/M (%)	2385/5112 (31.8/68.2)	10/52 (16.1/83.9)	0.008
COD (%)	4043/1246/1839	26/2/33	<0.001
Anoxia/stroke/trauma	(53.9/16.6/24.5)	(41.9/3.2/53.2)	
BMI (kg/cm^2)	23.8 (27.9–33.0)	27.4 (24.5–30.4)	0.04
DM	619 (8.3%)	0	0.046
HTN	2384 (31.8%)	4 (6.5%)	<0.001
Creatinine (mg/dL)	0.8 (0.6–1.1)	0.7 (0.6–1.0)	0.009
Recipient			
Age (y)	57 (46–65)	44 (35–55)	<0.001
BMI (kg/cm^2)	28.2 (24.6–32.5)	27.1 (22.8–31.6)	0.32
Re-KT	763 (10.2%)	6 (9.7%)	0.90
DM	3152 (42.0%)	22 (35.5%)	0.30
Waitlist time	517 (125–1241)	548.5 (56–1262)	0.90
SPK	41 (0.6%)	3 (4.8%)	<0.001
SLK	115 (1.5%)	4 (6.5%)	0.002
CIT (h)	19.5 (14.9–24.2)	16.5 (12.7–20.3)	0.004
Post-KT creatinine (1 y)	1.4 (1.1–1.7)	1.2 (1.0–1.4)	<0.001

Values are presented as the n (%) or median (IQR).
BMI, body mass index; CIT, cold ischemia time; COD, cause of death; DCD, donation after circulatory death; DM, diabetes mellitus; HTN, hypertension; IQR, interquartile range; KT, kidney transplantation; NRP, normothermic regional perfusion; SLK, simultaneous liver-kidney; SPK, simultaneous pancreas-kidney; TA-NRP, thoracoabdominal-NRP.

TABLE 8.
DCD pancreas donor and recipient demographics

Variables	DCD PT without TA-NRP (n = 41)	DCD PT with NRP (n = 3)	P
Donor			
Age (y)	22 (17–29)	21 (16–28)	0.76
Gender F/M (%)	9/ 32 (22.0/78.0)	0/ 3 (0/100)	0.36
COD (%)	17/3/18	1/0/2	0.85
Anoxia/stroke/trauma	(41.5/7.3/43.9)	(33.3/0/66.7)	
BMI (kg/cm^2)	23.2 (21.9–25.9)	21.6 (20.9–28.0)	0.81
Amylase (U/L)	52 (40–70)	134 (15–140)	0.48
Lipase (U/L)	41 (24–77)	7 (4–58)	0.40
Recipient			
Age (y)	45 (35–51)	40 (31–51)	0.59
BMI (kg/cm^2)	26.1 (24.6–28.6)	29.0 (24.8–29.9)	0.47
Waitlist time	103 (41–500)	474 (43–726)	0.88
SPK	35 (85.4%)	3 (100%)	0.48
CIT (h)	10.0 (8.0–13.6)	10.4 (8.4–13.4)	0.96

Values are presented as the n (%) or median (IQR).
BMI, body mass index; CIT, cold ischemia time; COD, cause of death; DCD, donation after circulatory death; F/M, female/male; IQR, interquartile range; NRP, normothermic regional perfusion; PT, pancreas transplantation; SPK, simultaneous pancreas-kidney; TA-NRP, thoracoabdominal-NRP.

TABLE 6.
Causes of graft loss/patient death after DCD LT

Cause of graft loss after DCD LT	DCD without TA-NRP (n = 169)	DCD with TA-NRP (n = 2)
Primary nonfunction	21	0
Cardiovascular disease	18	1
Infection	13	0
Vascular-related complications	9	0
Multiple organ failure	9	0
Biliary complication (IC)	8 (7)	0
Respiratory failure	8	0
Cerebrovascular disease	6	0
Malignancy	6	1
Rejection	6	0
Hemorrhage	4	0
Miscellaneous	17	0
Unspecified	29	0
Missing information	15	0

DCD, donation after circulatory death; IC, ischemic cholangiopathy; LT, liver transplantation; NRP, normothermic regional perfusion; TA-NRP, thoracoabdominal-NRP.

metrics.[31] Although fewer organs are transplanted from DCD donors than from DBD donors,[1] a recent study using the UK registry data reported that NRP significantly increased the utilization rates in all abdominal organs and overall organ yield in DCD donors.[13] Ex situ machine perfusion technology may lead to similar beneficial effects on organ yield for individual organs,[23] but such interventions are expensive and are organ specific.[13] Contrary to ex situ machine perfusion technology, NRP perfuses multiple organs, increasing all abdominal organ yield. Therefore, NRP can improve OPO performance in the new metrics by maximizing overall organ yield from DCD donors.

DCD transplant without TA-NRP experiences higher rates of complications compared with DBD transplantation, such as PNF and biliary complications in livers, PNF and DGF in kidneys, and thrombosis in pancreases.[6,7,13] The higher risks in DCD transplantation are attributed to warm ischemic insults between withdrawal of life support and the start of cold perfusion of the aorta.[9] NRP allows organ perfusion with oxygenated blood promptly after circulatory arrest. ATP concentrations are restored and warm ischemic insults are minimized, leading to improvement in posttransplant outcomes.[32] A multicenter retrospective study evaluating DCD KT demonstrated that NRP was associated with a significantly decreased risk for DGF and superior 1-y graft survival.[33] Similarly, in DCD LT, complications such as PNF and biliary complications have been minimized and superior graft survival was obtained by NRP.[9-11] In our national registry data including 24 LTs, 62 KTs, and 3 PTs from DCD with TA-NRP, there were only 2 liver grafts and 1 kidney graft failing within 1 y after transplantation. Although further exploration will be needed because of the small number in the TA-NRP group of our study, DCD with NRP transplant shows promise for acceptable outcomes after abdominal transplantation.

Although NRP in DCD has expanded graft utilization and improved outcomes after transplantation, the indication criteria of NRP have not yet been established. Although NRP is considered for all DCD procurements in several European countries, different preservation options, including with or without NRP or machine perfusion, are permitted in the

for transplant candidates, which was implemented on August 1, 2022.[31] This final rule would revise the outcome measures for assessing OPO performance by evaluation of donation rate and transplantation rate. Donors in the new metrics are defined as those with inpatient death, without excluding DCD donors. This change can serve to increase awareness and pursue all potential donors, even those who are only able to donate 1 organ. CMS estimates that approximately 5600 more organs per year are to be transplanted under the new

United States, United Kingdom, and Spain. Observational studies from Spain reported that NRP is inherently prone to be selected for older donors and high-risk donors because of the beneficial impact on transplant outcomes.[11,25] Likewise, a study from the United Kingdom demonstrated a greater proportion of DCD LT using NRP in donors classified as futile or high-risk for transplantation.[10] However, contrary to the NRP practice in European countries, we found that donor age in DCD with TA-NRP is significantly younger than that in DCD without TA-NRP: 27.5 versus 46 y. This is likely associated with the fact that the practice of TA-NRP in the United States is driven by heart transplant teams.[18,20] Although the impact of NRP on older donors cannot be evaluated in our study because of the lack of these populations, comparable outcomes are encouraging to expand the use of NRP in high-risk donors. A future standardized approach to defining the indication of NRP in the United States is warranted.

This study is limited by its retrospective design using national registry data. Although previous studies from European countries showed that donors with extended dWIT can be used for DCD LT after NRP, dWIT for TA-NRP cases were not available in our study. Because the practice of TA-NRP in the United States is driven by heart transplant teams,[20] there has been a selection bias for donors favorable for heart transplantation. Although propensity matching was used in our study, the selection bias is likely to be favoring the TA-NRP group. Additionally, the data do not include possible complications related to TA-NRP procedure. However, a case series of TA-NRP in the United States did not experience any complications attributed to the TA-NRP technique.[20] Furthermore, given that NRP can spare the need for rapid organ recovery, TA-NRP can decrease the risk of surgical injury related with rapid recovery technique.

In conclusion, TA-NRP in the United States significantly increased the utilization rate of abdominal organs from DCD donors, especially liver and pancreas grafts, with comparable outcomes after transplantation. By developing protocols to standardize NRP and establishing its indication, NRP in the United States may expand the donor pool without compromising transplant outcomes.

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