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Original Article

Normothermic regional perfusion performed by a United States organ procurement organization for nonthoracic organ donors

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ABSTRACT

Normothermic regional perfusion (NRP) has the potential to increase the number and quality of transplanted organs. Most reports showing the advantages of NRP have been from transplant centers, but not all centers perform NRP. These advantages could be broadened if organ procurement organizations (OPOs) also performed NRP. We report donation and transplantation outcomes of our first 90 OPO-based NRP nonthoracic donors, divided into 3 eras (n = 30 each). Comparisons were made with donation after circulatory determination of death direct procurement (DP; n = 270) and donation after brain death (DBD; n = 729) donors. NRP donor median age was 53 years, compared to DP (48 years, $P = .004$) and DBD (44 years, $P < .001$) donors. NRP liver utilization (69%, 18 accepting centers) was superior to DP (17%, $P < .001$) and not significantly different from DBD utilization (79%, $P = .27$) in multivariate analysis. By era, NRP liver utilization progressively increased: 53%, 70%, 83% ($P = .04$). NRP kidney use rate (71%) was higher than in DP (60%, $P = .02$) and not significantly different from DBD (76%, $P = .15$), especially among older donors. NRP kidney delayed graft function incidence (29%) was lower than in DP (47%, $P = .001$) and not significantly different from DBD (32%, $P = .53$) donors. OPO-based NRP can provide more livers and kidneys to multiple transplant centers and improve outcomes from nonthoracic organ donors.

Abbreviations: A-NRP, abdominal normothermic regional perfusion; DBD, donation after brain death; DCD, donation after circulatory determination of death; DGF, delayed graft function; DP, direct procurement; DSA, donation service area; HMP, hypothermic machine perfusion; KDPI, kidney donor profile index; NMP, normothermic machine perfusion; NRP, normothermic regional perfusion; OPO, organ procurement organization; OPTN, Organ Procurement and Transplantation Network; OR, operating room; PNF, primary nonfunction; PRBC, packed red blood cell; SBP, systolic blood pressure; TA-NRP, thoracoabdominal normothermic regional perfusion.

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1. Introduction

Normothermic regional perfusion (NRP) provides higher quality and more organs for transplantation.[1-18] To our knowledge, all reports documenting the clinical benefits of NRP in the US and internationally are from transplant centers.[4,6-9,11,12,14-16] NRP could have a broader positive impact if organ procurement organizations (OPOs) also developed NRP capability, as a transplant center that performs NRP: (1) might not have a candidate on the match run for a donation after circulatory determination of death (DCD) donor, or (2) declines the organ(s) being offered.

We had coordinated NRP recoveries for our local heart transplant program and were aware of the abdominal organ recipient benefits from their and others' efforts.[9,16] With guidance from abdominal transplant center–based NRP programs,[4,5,17] we sought to better serve candidates appearing on match runs in our donation service area (DSA) with an OPO-based NRP program for nonthoracic DCD donors. We describe herein kidney and liver donation and early posttransplant outcomes of our initial NRP experience compared to DCD direct procurement (DP; rapid aortic cross-clamping and allograft explantation) and donation after brain death (DBD) donors.

2. Methods

2.1. Program development

Program development first involved the identification of 2 internal NRP "champions" whose collective professional time and effort became predominantly NRP-focused, identifying expected necessary operational changes, developing process standards, and educating individual department leaders (Clinical Services, Hospital Development, Family Care) on the expected operational impact to their respective staffs. Mandatory in-person staff training sessions were held to standardize practices. Surgically, we simulated thoracic and abdominal cannulations in a research- and education-authorized tissue donor. We developed a contractual agreement with a third-party company of certified clinical perfusionists. The interval from committing to developing NRP capability to the first recovery was approximately 6 months. Subsequent practical experience and ongoing evaluation identified areas where process refinements were indicated and these refinements were communicated in real-time, as necessary, and in biweekly staff-wide case review sessions.

An important early recognized deficit included inefficient navigation of DonorNet declines of livers we thought were transplantable. This was addressed by hosting a meeting with 7 liver transplant program leaders who had established themselves as willing to accept livers after multiple or late declines by others. We learned what NRP-specific information would be helpful to all transplant programs, especially in the expedited setting, and refined our process accordingly; this was succeeded by improved liver utilization as experience grew (see details below).

2.2. Study endpoints and methodology

All data were prospectively recorded for purposes other than this study and deidentified prior to analyses. It was granted institutional review board exemption status by an external institutional review board.

The primary endpoint was liver utilization rate (number of livers transplanted divided by all donors); the secondary endpoint was kidney use rate (all kidneys transplanted divided by the number of kidneys intended for transplantation). These endpoints were compared between 3 recovery types: NRP, DP, and DBD. Liver intent was defined as having the liver provisionally accepted by a transplant center prior to recovery. Kidney-intent mirrored Organ Procurement and Transplantation Network (OPTN) kidney-eligible criteria.[19]

All NRP donors had the intent to recover only abdominal organs for transplantation and were performed exclusively by OPO-employed personnel (surgeon, organ preservationists who first-assisted) from July 8, 2023, through July 10, 2024; perfusion services were provided by the contracted certified clinical perfusionists. Recoveries of abdominal organs from DBD and DP donors were performed by the OPO surgeon and non-OPO surgeons; these non-NRP recoveries were from January 1, 2022, through July 10, 2024. The beginning of this time period coincided with the OPO surgeon's hiring to enhance surgical coverage for growing donation opportunities, particularly for DCDs; the number of DCDs had almost tripled from 2018 ($n = 43$) to 2021 ($n = 119$). DP and DBD cohorts included thoracic and nonthoracic donors.

To document the effect of evolving practice, the NRP cohort was divided into 3 eras of equal number of recoveries. As our NRP focus was on nonthoracic donors, NRP donors where the heart was recovered (and cannulation was performed by the heart transplant center) were excluded. All DP and NRP donors were controlled DCD (Maastricht type III).[20]

Primary nonfunction (PNF) of NRP livers and delayed graft function (DGF) of all kidneys were recorded. PNF was defined according to OPTN criteria and was acquired (as part of routine OPO protocol) through follow-up with liver recipient centers.[19] DGF was defined as needing dialysis within 7 days of transplantation and was acquired (as part of routine OPO protocol) through follow-up with kidney recipient centers and/or through the OPTN. Other recorded data included: donor demographics; match kidney donor profile index (KDPI); NRP designation (thoracoabdominal normothermic regional perfusion [TA-NRP]; abdominal normothermic regional perfusion [A-NRP]); duration of NRP; last prerecovery hematocrit; packed red blood cell (PRBC) utilization; SBP50 interval (time from first systolic blood pressure (SBP) <50 mmHg to NRP initiation)[21,22]; interval between skin incision and operating room (OR) exit; and surgical injury incidence for DP and NRP kidneys. If the liver was placed on normothermic machine perfusion (NMP) in the door OR, this was recorded; we did not routinely capture if hypothermic machine perfusion (HMP) or NMP was employed by the center after receiving the liver ("back to base"). We also recorded the number of attempted DP and NRP donors who did not die within the accepted timeframe to donate.

2.3. NRP techniques

2.3.1. Cannulation

The body region perfused defined NRP designation. TA-NRP sequentially included sternotomy, en mass clamping of the aortic arch vessels, venting (transection) of the innominate artery, right atrium/IVC cannulation, ascending aorta cannulation, and NRP initiation. After initially (first 6 cases) cannulating the distal abdominal aorta and IVC near the iliac vein confluence, A-NRP evolved to arterial/venous cannulation in the external iliac vessels, clamping/venting the descending thoracic aorta (via sternotomy or left thoracotomy), and NRP initiation. This evolution was due to experience in our seventh A-NRP donor who had a type A aortic dissection extending into bilateral common iliac arteries and the need to ensure cannulation distal to the intimal flap; the noted ease of access and smaller area of dissection at risk for bleeding led to iliac cannulation in all subsequent A-NRP recoveries. No premortem cannulation (except in donors on venous-arterial extracorporeal membrane oxygenation) was done. All cannulations were performed exclusively by the OPO team, and the clamp/vent times were recorded in the donor record. Step-by-step descriptions of our NRP techniques are in Supplementary Methods.

Regardless of NRP designation, the NRP pump was a Medtronic Bio-Console 560 centrifugal pump with a single drainage reservoir. The target flow was a cardiac index of 2.5 to 3.0 liters per minute per meter squared. A single certified clinical perfusionist was used for each case, as was a "cell saver" suction(s) for scavenging blood and returning it to the circuit via the reservoir. The composition of the pump priming fluid is in Supplementary Methods.

2.3.2. Recovery

Our current NRP recovery technique does not mimic recovery in DBD donors. Because of inevitable cumulative blood loss on anticoagulation and the occasional need to extend NRP duration for liver reallocation, our technique evolved to doing no dissection after initiating NRP beyond that necessary to assess the liver until it was accepted or definitively declined and we were planning to cross-clamp. Once/if the liver was accepted, we cannulated the portal system (usually the inferior mesenteric vein) for eventual cold portal perfusion and did minimal porta hepatis dissection in preparation for cross-clamp. The aortic/arterial NRP cannula was used for cold perfusion (no separate aortic cannulation was needed), and exsanguination was through the venous cannula.

2.3.3. Liver assessment and NRP duration

Gross liver assessment was supplemented by serial point-of-care serum lactate measurements: 5 minutes after NRP initiation and every 15 to 20 minutes thereafter until the liver was accepted or deemed unsuitable for transplantation. NRP was arbitrarily planned for 60 minutes in liver-intent donors and 45 minutes if only kidneys were being recovered for transplantation; the final determinant of NRP duration depended on liver disposition: if we felt the liver was transplantable (regardless of liver intent) we stayed on NRP until the liver was accepted or had exhausted the list; if accepted and necessary, we prolonged perfusion for the center to get their recipient admitted and/or ready for transplantation and/or to arrange liver transportation logistics, during which no further lactate levels were checked.

2.4. Statistical analysis

Categorical variables are described as percentages, and continuous variables as median (interquartile range). Categorical variables were compared using chi-square or Fisher exact test, and continuous variables using the Student *t* test or the Mann-Whitney *U* test, as appropriate. Continuous variables by era were compared using the Kruskal-Wallis test. Where appropriate, the independent impact of recovery type on liver utilization was tested with multivariate logistic regression. A 2-sided *P* value $\leq$ .05 was considered significant. Statistical analyses were performed with Stata, version 18.0 (StataCorp).

3. Results

3.1. NRP cohort

The first 90 OPO-based NRP donors with the intent to recover only abdominal organs comprise the NRP cohort; 42 (47%) were female. Median age was 53 (44-59) years (Table 1) and did not

Table 1
Descriptive data, donation outcomes, and kidney recipient DGF for 3 donation cohorts (NRP, DP, DBD).

Variable	NRP (n = 90)	DP (n = 270)	DBD (n = 729)
Age (y)	53 (44-59)	48 (37-57)	44 (32-54)
		$P = .004$[a]	$P < .001$[a]
Female (%)	47	35	39
		$P = .06$[a]	$P = .17$[a]
BMI (kg/m^2)	30.85 (25.7-38.3)	29.05 (24.0-35.9)	27.7 (23.7-32.9)
		$P = .09$[a]	$P < .001$[a]
Liver utilization	69	17	79
(%)		$P < .001$[b]	$P = .27$[b]
Match KDPI (%)[c]	70 (57-85)	67 (46-82)	53 (30-77)
		$P = .11$[a]	<0.001[a]
Kidney use (%)[c]	71	60	76
		$P = .02$[a]	$P = .15$[a]
DGF (%)	29	47	32
		$P = .001$[a]	$P = .53$[a]

Continuous variables are expressed as median (IQR).
BMI, body mass index; DBD, donation after brain death; DGF, delayed graft function; DP, direct procurement; IQR, interquartile range; KDPI, kidney donor profile index; NRP, normothermic regional perfusion.

[a] Compared to NRP, univariate.

[b] Compared to NRP, multivariate logistic regression, adjusted for BMI (DP) or age and BMI (DBD).

[c] Excludes donors with no kidney intent.

vary significantly by era (Table 2). During the study period, 47 NRP-intended donors did not die within the accepted timeframe to donate; this equated to 34% (47/137) of NRP-intended donors.

Era 1 (donors 1-30) ended on December 15, 2023; only 5 NRP recoveries were performed (0 livers transplanted) before October 1, 2023, after which it became our strategy to perform NRP, when feasible, on every DCD donor. Era 2 (donors 31-60) ended on March 24, 2024. Era 3 (donors 61-90) ended on July 10, 2024.

The median SBP50 interval was 15 (12-19) minutes and did not vary significantly by era (Table 2). NRP was successfully initiated on all attempts.

3.2. DP and DBD cohorts

There were 270 DP donors; 95 (35%) were female; the median age was 48 (37-57) years ($P = .004$ compared to NRP; Table 1). There were 197 potential DP donors who did not die within the accepted timeframe to donate; this equated to 42% (197/467) of DP-intended donors ($P = .11$ compared to NRP-intended donors). There were 729 DBD donors; 286 (39%) were female; the median age was 44 (32-54) years ($P < .001$ compared to NRP; Table 1).

3.3. Liver outcomes

NRP livers (n = 62) were transplanted at 18 centers. The single local (within our DSA) center transplanted 21 livers; the range otherwise was 1 to 8 livers. The median match run sequence for local and nonlocal centers was 5 (2-18) and 107 (19-336), respectively ($P < .001$). NMP was initiated on 5 livers in the donor OR; all were transplanted.

Livers were transplanted from 55 (75%) of 73 NRP donors with liver intent. Livers were transplanted from 7 (41%) of 17 donors with no liver intent—after finding a suitable liver in the OR and reallocating it, including from our oldest (72 years) donor. These 7 livers were evenly distributed across eras (n = 2, n = 3, and n = 2, respectively). There were 5 donors with liver-only intent; their median age was 61 (range 41-67) years; 4 (80%) of these livers were transplanted, none of which were placed on NMP in the donor OR.

Overall NRP liver utilization was 69% (62 of 90; Tables 1 and 2, Figs. 1 and 2) and significantly increased by era: 53%, 70%, and 83%, respectively (Table 2, Fig. 2). Of the 5 livers not transplanted in era 3, all were deemed nontransplantable (cirrhosis, trauma, steatosis). By age, 57 donors were older than 50 years, from whom 42 (74%) livers were transplanted; 20 donors were older than 60 years, from whom 16 (80%) livers were transplanted. The median match run sequence at transplantation was 31.5 (5-237) and did not significantly vary by era (Table 2).

DP liver utilization was 17% (46 of 270; Table 1, Fig. 1). Adjusting for the single other factor predicting liver utilization (body mass index, $P = .003$), the NRP odds ratio for liver transplantation was 15.8 (95% CI 8.5-20.3; $P < .001$). NMP was initiated on 12 DP livers in the donor OR; all were transplanted. DP donors without liver intent had 0 livers transplanted ($P < .001$ compared to NRP). Three DP donors had liver-only intent ($P = .03$ compared to NRP); all 3 livers were transplanted, 1 with the benefit of NMP.

DBD liver utilization was 79% (577 of 729; Table 1, Fig. 1). Adjusting for age and body mass index, both of which were significant univariate predictors of liver utilization ($P < .001$ and $P = .002$, respectively), DBD did not significantly predict liver utilization (odds ratio 1.3, 95% CI 0.80-2.19, $P = .27$). Further, excluding DBD heart donors resulted in a DBD median age of 52 (41-59) years ($P = .22$ compared to NRP); liver utilization in this subgroup was 74% (347 of 468), not significantly different from NRP overall (69%, $P = .30$) or in era 3 (83%, $P = .39$). DBD donors over 50 and 60 years old had 75% and 74% liver utilization rates ($P = .87$ and .78 compared to NRP), respectively.

PNF occurred in 2 NRP recipients; the transplant teams attributed each primarily to events in the recipient OR and did not report the event to us until we requested follow-up. The donors were 40 and 50 years old; lactate levels went from 8.0 to 6.8 and 9.8 to 8.1; SBP50 intervals were 14 and 20 minutes; and NRP durations were 97 and 154 minutes, respectively. The livers were grossly and microscopically unremarkable; neither recovery required PRBC transfusion; and each recovery was uneventful.

3.4. Kidney outcomes

Kidney intent was present in 85 NRP donors (170 kidneys); kidney intent applied to 531 DP and 1372 DBD kidneys. Table 1 shows the median match of KDPI and kidney use rates by cohort. The kidney use rate from NRP donors was significantly higher than from DP donors, despite significantly younger DP donors.

Table 2
NRP cohort data, overall and by era.

Variable	All NRP (n = 90)	Era 1 (n = 30)	Era 2 (n = 30)	Era 3 (n = 30)	*P* value
Age (y)	53 (44-59)	52.5 (44-57)	53.5 (48-61)	51.5 (44-59)	.46
Liver utilization (%)	69 (n = 62)	53 (n = 16)	70 (n = 21)	83 (n = 25)	.04
SBP50 interval (min)	15 (12-19)	15 (13-20)	15.5 (11-18)	14 (12-19)	.45
NRP duration (min)	88.5 (66-127)	99.5 (63-142)	88 (73-110)	79 (66-109)	.61
PRBC transfusion (%)	24 (n = 22)	33 (n = 10)	27 (n = 8)	13 (n = 4)	.19
Liver recipient match run sequence	31.5 (5-237)	38.5 (5-553.5)	59 (13-107)	18 (4-237)	.65

Continuous variables are expressed as median (IQR).
IQR, interquartile range; NRP, normothermic regional perfusion; PRBC, packed red blood cell; SBP, systolic blood pressure.

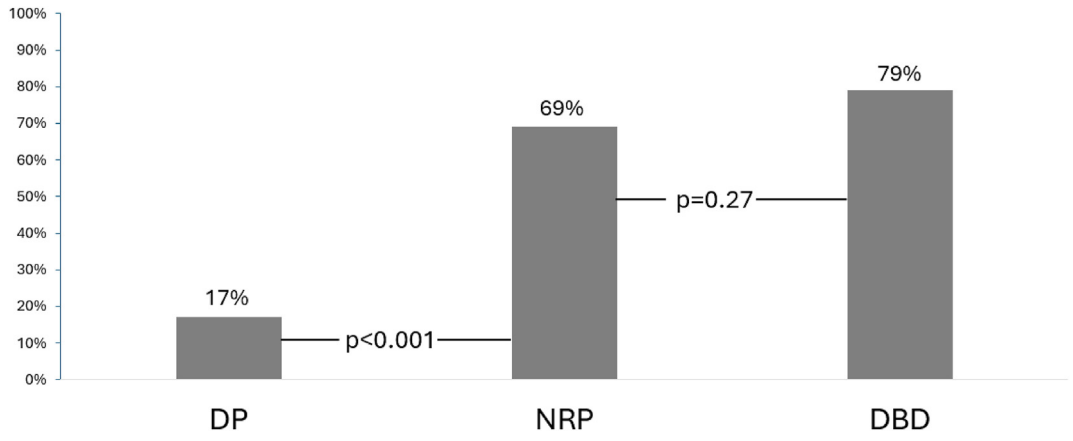

Figure 1. Liver utilization by recovery cohort (%). DBD, donation after brain death; DP, direct procurement; NRP, normothermic regional perfusion.

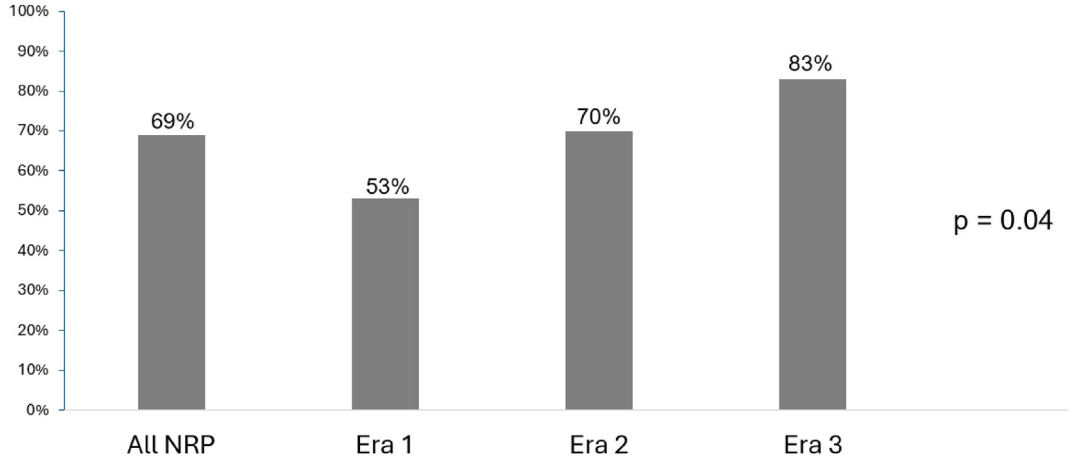

Figure 2. Normothermic regional perfusion (NRP) liver utilization by era (%).

Additionally, in donors aged over 50 years, the NRP kidney use rate was 61%, compared to DP (28%; $P < .001$) and DBD (54%; $P = .16$).

DGF incidence was 29% in NRP kidneys, significantly lower than in DP (47%) and not significantly different from DBD (32%) kidneys (Table 1). There were no surgical kidney injuries in the NRP cohort, compared to 3.8% (20 of 531, $P = .006$) in the DP cohort.

3.5. NRP parameters and operational impact on donor hospitals

The median NRP duration overall was 88.5 (66-127) minutes. By era, median durations were 99.5, 88, and 79 minutes, respectively (Table 2). The maximum duration was 269 minutes (in era 2). NRP duration was over 180 minutes in 8 recoveries, including 3 recoveries with a duration over 240 minutes; all 8 livers were transplanted, none of which were placed on NMP in the donor OR.

The median time from incision to OR exit was 188 (159-227) minutes in the NRP group, compared to 94 (80-114) minutes in the DP group ($P < .001$). For consistency, DPs performed by non-OPO surgeons were excluded from this analysis, as were donors when the liver was placed on NMP before OR exit.

PRBC transfusion was required to maintain target blood flow and/or due to the perceived need to increase oxygen delivery in 22 (24%) donors. Of the 22 PRBC transfused donors, 9 (41%) got 1 unit. Transfusion by era is shown in Table 2; in 3 of the 4 transfused era 3 donors, the initial on-circuit hematocrit was <15%. The median number of units transfused overall was 0 (0-0); for those who got transfused, the median number of units was 2 (1-3); total PRBC utilization for the series was 48 units. The need for transfusion was significantly related to NRP duration ($P = .03$) but not to the last recorded prerecovery hematocrit ($P = .29$) or any other tested variable.

4. Discussion

To our knowledge, this is the first published report of NRP recoveries executed solely by an OPO in the US. Though our NRP program was self-reliant, it was invaluably informed through discussions with and insight from key personnel from successful transplant center–based NRP programs.[4,5,17] This insight informed the planning and preparation outlined in the Methods section "Program development" above. We feel all components described in that outline were equally necessary and critical to our outcomes. Noteworthy, the one-surgeon model described herein, although optimal for initially developing DSA-wide

consistency, inevitably strains logistics and risks underachieving NRP potential. Realizing the benefits of our NRP efforts, the ongoing increase in DCD opportunities, and the inherent logistical challenges (eg, overlapping cases, donor family time constraints) led us to hire and train another surgical provider. In addition, we now partially rely on nonemployed transplant/recovery surgeons, one of whom was previously cannulation-proficient; we trained 2 others in the components of NRP cannulation and execution, including the nuances we learned that differ between NRP and DBD dissection/recovery techniques. The perfusion company has been able to cover overlapping cases, and we have not had to utilize another provider for perfusion services.

Our results showed NRP liver utilization to be superior to DP and not significantly different from DBD liver utilization, particularly in older donors and after program maturation. Even though our DP liver utilization rate (17%) during the study period was lower than that seen nationally (21% in 2022; 29% in 2023) our NRP liver utilization rate (69% overall; 83% in era 3) indicates substantial NRP potential.[23] Similarly, NRP kidney use was superior to DP and not significantly different from DBD kidney use, especially in older donors. Moreover, the overall liver and kidney donation and early posttransplant outcomes were achieved despite having significantly older NRP donors compared to both other cohorts.

Increased liver utilization is a compelling reason for an OPO to develop an NRP program for nonthoracic donors. We successfully allocated 7 (41%) of 17 livers after the list had been exhausted prerecovery; all of these would have predictably been discarded, as this had never happened in our DP donors. These NRP donors without liver intent accounted for over 10% of our total liver utilization, which offers a rationale for performing NRP in donors with kidney-only intent.

In addition to increased liver utilization, our NRP kidney use rate was significantly higher than in the DP cohort and not significantly different from that in the DBD cohort, despite significantly older NRP donors. Moreover, the NRP kidney DGF rate was significantly lower (compared to DP) or not significantly different (compared to DBD), despite the same negative bias, and the incidence of surgical injury was significantly less compared to DP kidneys. Higher kidney use and lower likelihoods of DGF and surgical injury are additional reasons for OPOs to develop an NRP program for nonthoracic donors, including those with kidney-only intent.

Collectively, the above-mentioned reasons support OPO-based NRP. It is worth reemphasizing that our program was inspired and informed by abdominal transplant center–based programs,[4,5,7,17,24] some of which provided guidance in technique and process development. Because of the clinical advantages associated with NRP, OPOs can be encouraged to develop an NRP program internally for nonthoracic donors, perhaps learning from, as we did, and/or partnering with an equally committed transplant center(s). Advantages of such collaboration with a local transplant center(s) include: (1) protocols can be codeveloped to enhance standardization of practices throughout a DSA; and (2) the OPO's ability to rely on transplant center surgical expertise for cannulation and recovery, including for livers being exported, without having to develop this expertise internally.

Regardless of the clinical benefits noted here and elsewhere, NRP has "costs." NRP requires additional personnel, although our protocol required only one more person (the certified clinical perfusionist) than in a DP recovery. There are financial costs associated with the disposables and the circuit priming components; these are at least partially offset by the additional organs transplanted and the lower need for dialysis posttransplant demonstrated here and by others,[6,10-14,17,18,25-28] and the financial burden is usually allocated across 3 organs. NRP has also been shown to be financially favorable to other advanced perfusion strategies.[1] Notably, the additional time in the OR (median 188 vs 94 minutes) compared to DP is an important potential strain on donor hospitals and their OR staff. Also from the donor hospital perspective, NRP (and NMP) allows planning of recoveries from donors that, in the past, would not have been considered as having donation potential (eg, the liver-only intent donors). Given the demonstrated significant impact on waitlisted candidates and posttransplant outcomes, these collective burdens are arguably not prohibitive. An often unrecognized "cost" in DCD donation is a decrease in OPO and/or donor hospital staff morale after a potential donor does not die within the accepted timeframe. We did not experience this disproportionately with NRP-intended donors, who had a lower (though not significant) likelihood of timing out.

NRP and NMP can be complementary as shown here and by others, and the combination is often advisable.[29] We do not know how often HMP or NMP was employed in the "back to base" setting, and we did not record a transplant center's rationale for employing NMP in the 12 DP recoveries or 5 NRP recoveries. Once we started performing NRP, a transplant center's plan to employ liver NMP did not influence our decision to pursue NRP—although the liver benefit is derived from NRP and NMP, kidney benefits are unique to NRP. In our study, these benefits included more kidneys transplanted and better recipient outcomes, particularly from older donors. Additionally, NRP potentially increases the number of reallocation destinations, as all programs might not desire NMP.

Our surgical protocol deserves discussion. Although some surgical steps have been refined to our current protocols in Supplementary Methods, we have always honored as sovereign the principle of ensuring absent intracranial blood flow. This included mechanical clamping of the aortic arch vessels (TA-NRP) or descending thoracic aorta (A-NRP) and venting the innominate artery or aorta, respectively, between the clamp and intracranial vasculature in all donors. We never relied on clamping alone. We are aware of a study investigating the need for venting,[30] but we found venting to be relatively effortless and not create any undue hassles. Until more data prove beyond a reasonable doubt that it is not necessary, venting will remain a cornerstone of our surgical approach.

Our study has limitations. As above, we do not have data on the use of "back to base" HMP or NMP, but these modalities are available to all donors and should not disproportionately favor

NRP. As an OPO, we also do not have timely or granular recipient outcome data (eg, biliary and/or other complications, posttransplant length of stay, graft or patient survival data). It is already known, however, that NRP favorably impacts those outcomes.[3,7,8,12] All cohorts are retrospective, and, consequently, there could be biases between the groups not accounted for in our analyses; specifically, the NRP cohort was disproportionately more current than the DP and DBD cohorts, possibly favoring NRP outcomes. Statistically, even though we showed no significant difference between NRP and DBD kidney and liver outcomes, this study was not powered to claim noninferiority of NRP compared to DBD or vice-versa; the small sample size (n = 30) of each NRP era hinders comparisons between DP and DBD with the most recent (era 3) NRP outcomes. Well-designed, prospective trials to definitively compare these donor types are lacking. Despite these limitations, we believe our data support previous studies showing significantly increased organ availability and quality from NRP donors.[1-18]

In conclusion, this study adds data that NRP has significant potential to improve liver and kidney donation and transplantation outcomes from DCD donors and reduce waitlist mortality, despite worse donor characteristics (eg, age, KDPI). More data are needed to better compare the outcomes of NRP organs to DBD organs.

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Declaration of competing interest

The authors of this manuscript have no conflicts of interest to disclose as described by *American Journal of Transplantation*.

Data availability

Data will be made available upon reasonable request to Deana C. Clapper and Marty T. Sellers.

Appendix A. Supplementary data

Supplementary data to this article can be found online at https://doi.org/10.1016/j.ajt.2025.04.005.

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References

1. Bakhtiyar SS, Maksimuk TE, Gutowski J, et al. Association of procurement technique with organ yield and cost following donation after circulatory death. *Am J Transplant*. 2024;24(10):1803–1815. https://doi.org/10.1016/j.ajt.2024.03.027.
2. Bekki Y, Croome KP, Myers B, Sasaki K, Tomiyama K. Normothermic regional perfusion can improve both utilization and outcomes in DCD liver, kidney, and pancreas transplantation. *Transplant Direct*. 2023;9(3):e1450. https://doi.org/10.1097/TXD.0000000000001450.
3. Brubaker AL, Sellers MT, Abt PL, et al. US liver transplant outcomes after normothermic regional perfusion vs standard super rapid recovery. *JAMA Surg*. 2024;159(6):677–685. https://doi.org/10.1001/jamasurg.2024.0520.
4. Brubaker AL, Taj R, Jackson B, et al. Early patient and liver allograft outcomes from donation after circulatory death donors using thoracoabdominal normothermic regional: a multi-center observational experience. *Front Transplant*. 2023;2:1184620. https://doi.org/10.3389/frtra.2023.1184620.
5. Croome KP, Brown TE, Mabrey RL, et al. Development of a portable abdominal normothermic regional perfusion (A-NRP) program in the United States. *Liver Transpl*. 2023;29(12):1282–1291. https://doi.org/10.1097/LVT.0000000000000156.
6. Demiselle J, Augusto JF, Videcoq M, et al. Transplantation of kidneys from uncontrolled donation after circulatory determination of death: comparison with brain death donors with or without extended criteria and impact of normothermic regional perfusion. *Transpl Int*. 2016;29(4):432–442. https://doi.org/10.1111/tri.12722.
7. Hessheimer AJ, Coll E, Torres F, et al. Normothermic regional perfusion *vs*. super-rapid recovery in controlled donation after circulatory death liver transplantation. *J Hepatol*. 2019;70(4):658–665. https://doi.org/10.1016/j.jhep.2018.12.013.
8. Hessheimer AJ, de la Rosa G, Gastaca M, et al. Abdominal normothermic regional perfusion in controlled donation after circulatory determination of death liver transplantation: outcomes and risk factors for graft loss. *Am J Transplant*. 2022;22(4):1169–1181. https://doi.org/10.1111/ajt.16899.
9. Hoffman JRH, McMaster WG, Rali AS, et al. Early US experience with cardiac donation after circulatory death (DCD) using normothermic regional perfusion. *J Heart Lung Transplant*. 2021;40(11):1408–1418. https://doi.org/10.1016/j.healun.2021.06.022.
10. Merani S, Urban M, Westphal SG, et al. Improved early post-transplant outcomes and organ use in kidney transplant using normothermic regional perfusion for donation after circulatory death: national experience in the US. *J Am Coll Surg*. 2024;238(1):107–118. https://doi.org/10.1097/XCS.0000000000000880.
11. Motter JD, Jaffe IS, Moazami N, et al. Single center utilization and post-transplant outcomes of thoracoabdominal normothermic regional perfusion deceased cardiac donor organs. *Clin Transplant*. 2024;38(3):e15269. https://doi.org/10.1111/ctr.15269.
12. Oniscu GC, Mehew J, Butler AJ, et al. Improved organ utilization and better transplant outcomes with in situ normothermic regional perfusion in controlled donation after circulatory death. *Transplantation*. 2023;107(2):438–448. https://doi.org/10.1097/TP.0000000000004280.
13. Padilla M, Coll E, Fernández-Pérez C, et al. Improved short-term outcomes of kidney transplants in controlled donation after the circulatory determination of death with the use of normothermic regional perfusion. *Am J Transplant*. 2021;21(11):3618–3628. https://doi.org/10.1111/ajt.16622.
14. Pearson R, Geddes C, Mark P, Clancy M, Asher J. Transplantation of kidneys after normothermic perfusion: a single center experience.

Clin Transplant. 2021;35(10):e14431. https://doi.org/10.1111/ctr.14431.
15. Sellers MT, Nassar A, Alebrahim M, et al. Early United States experience with liver donation after circulatory determination of death using thoraco-abdominal normothermic regional perfusion: a multi-institutional observational study. *Clin Transplant*. Jun 2022;36(6):e14659. https://doi.org/10.1111/ctr.14659.
16. Smith DE, Kon ZN, Carillo JA, et al. Early experience with donation after circulatory death heart transplantation using normothermic regional perfusion in the United States. *J Thorac Cardiovasc Surg*. 2022;164(2):557–568.e1. https://doi.org/10.1016/j.jtcvs.2021.07.059.
17. Wall A, Rosenzweig M, McKenna GJ, Ma TW, Asrani SK, Testa G. Six-month abdominal transplant recipient outcomes from donation after circulatory death heart donors: a retrospective analysis by procurement technique. *Am J Transplant*. 2023;23(7):987–995. https://doi.org/10.1016/j.ajt.2023.04.021.
18. Zhou AL, Leng A, Ruck JM, Akbar AF, Desai NM, King EA. Kidney donation after circulatory death using thoracoabdominal normothermic regional perfusion: the largest report of the United States experience. *Transplantation*. 2024;108(2):516–523. https://doi.org/10.1097/TP.0000000000004801.
19. Organ Procurement and Transplantation Network. Policies. Accessed March 29, 2025. https://optn.transplant.hrsa.gov/media/eavh5bf3/optn_policies.pdf.
20. Kootstra G, Daemen JH, Oomen AP. Categories of non-heart-beating donors. *Transplant Proc*. 1995;27(5):2893–2894.
21. Croome KP, Barbas AS, Whitson B, et al. American Society of Transplant Surgeons recommendations on best practices in donation after circulatory death organ procurement. *Am J Transplant*. 2023;23(2):171–179. https://doi.org/10.1016/j.ajt.2022.10.009.
22. Croome K, Bababekov Y, Brubaker A, et al. American Society of Transplant Surgeons normothermic regional perfusion standards: abdominal. *Transplantation*. 2024;108(8):1660–1668. https://doi.org/10.1097/TP.0000000000005114.
23. Organ Procurement and Transplantation Network. National data. Accessed March 29, 2025. https://optn.transplant.hrsa.gov/data/view-data-reports/build-advanced/.
24. Hunt F, Johnston CJC, Coutts L, et al. From haphazard to a sustainable normothermic regional perfusion service: a blueprint for the introduction of novel perfusion technologies. *Transpl Int*. 2022;35:10493. https://doi.org/10.3389/ti.2022.10493.
25. Artiles Medina A, Burgos Revilla FJ, Álvarez Nadal M, Muriel García A, Álvarez Díaz N, Gómez dos Santos V. Comparison of in situ preservation techniques for kidneys from donors after circulatory death: a systematic review and meta-analysis. *Transl Androl Urol*. 2021;10(8):3286–3299. https://doi.org/10.21037/tau-21-236.
26. Ghoneima AS, Sousa Da Silva RX, Gosteli MA, Barlow AD, Kron P. Outcomes of kidney perfusion techniques in transplantation from deceased donors: a systematic review and meta-analysis. *J Clin Med*. 2023;12(12):3871. https://doi.org/10.3390/jcm12123871.
27. Klein Nulend R, Hameed A, Singla A, et al. Normothermic machine perfusion and normothermic regional perfusion of DCD kidneys before transplantation: a systematic review. *Transplantation*. 2025;109(2):362–375. https://doi.org/10.1097/TP.0000000000005132.
28. Ramirez P, Vázquez D, Rodríguez G, et al. Kidney transplants in controlled donation following circulatory death, or Maastricht type III donors, with abdominal normothermic regional perfusion, optimizing functional outcomes. *Transplant Direct*. 2021;7(8):e725. https://doi.org/10.1097/TXD.0000000000001174.
29. Croome KP, Subramanian V, Mathur AK, et al. Outcomes of DCD liver transplant using sequential normothermic regional perfusion and normothermic machine perfusion or NRP alone versus static cold storage. *Transplantation*. 2025;109(7):1184–1190. https://doi.org/10.1097/TP.0000000000005301.
30. Frontera JA, Lewis A, James L, et al. Thoracoabdominal normothermic regional perfusion in donation after circulatory death does not restore brain blood flow. *J Heart Lung Transplant*. 2023;42(9):1161–1165. https://doi.org/10.1016/j.healun.2023.05.010.