Featured Article

Developing a thoracoabdominal normothermic regional perfusion (TA-NRP) program for the recovery of organs for thoracic transplant: lessons from the United States experience

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Background: Heart and lung transplantation remain efficacious treatments for patients with end-stage cardiopulmonary failure. However, donor shortages remain a challenge to both providers and patients. Thoracoabdominal normothermic regional perfusion (TA-NRP) has been increasingly adopted to decrease organ ischemia from circulatory death donors and therefore increase the number of organs available for transplantation. Despite initial success, data on program genesis and implementation are limited. The aim of this manuscript is to characterize essential human resources, lessons, and key considerations needed to improve TA-NRP dissemination and thus adoption.

Methods: Single-center evaluation of a TA-NRP program was conducted using a retrospective cohort study design. All procurements performed using TA-NRP were included. Quantitative data were summarized. Descriptive elements of programmatic genesis, implementation, and experience were summarized using an inductive reasoning approach.

Results: Thirty TA-NRP procurements were performed. The average time from incision to TA-NRP initiation was 7±2 minutes and total time on TA-NRP was 87±28 minutes. In simple regression analysis, the average total TA-NRP time was noted to increase by approximately 0.86 minutes per procurement [95% confidence interval (CI): −0.10, 1.82, P=0.08], while the average warm ischemia time was noted to decrease by approximately 0.03 minutes per procurement (95% CI: −0.13, 0.07, P=0.43). Key programmatic elements during planning and implementation were identification of key stakeholders, early communication, proactive navigation of ethical concerns, staffing and equipment needs, and development of TA-NRP algorithms for pre, intra- and post-donation phases of care.

Conclusions: Development of a TA-NRP program is both feasible and easily implemented at institutions with pre-existing organ donation after circulatory death (DCD) procurement experience. Early identification of key stakeholders with frequent communication identified areas in need of expanded resources and addressed early ethical concerns, while local implementation efforts supported operationalization of existing infrastructure for TA-NRP procurements.

Keywords: Normothermic regional perfusion (NRP); heart transplant; lung transplant; organ donation; organ recovery

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Introduction

Heart and lung transplantation remain efficacious treatments for patients with end-stage cardiopulmonary failure, representing the culmination of decades of research and both resource utilization and coordination across health systems (1-3). Despite such advances, ongoing donor shortages remain a challenge to both providers and patients, highlighting the need for innovation. To address this shortage of thoracic organs available for transplantation, many centers have sought to increase the use of organ donation after circulatory death (DCD); however, warm ischemia times remain a concern for organ quality and patient outcomes (4). In response to these concerns, thoracoabdominal normothermic regional perfusion (TA-NRP) has been increasingly adopted as a procurement technique aimed to reduce the degree of irreversible organ damage from ischemia and thus address many of the historical concerns of DCD donation (5,6).

While early results have demonstrated promise, ethical concerns and regulatory limitations have prevented widespread adoption, resulting in limited data and center experience (6-10). Despite such challenges, TA-NRP has been increasingly utilized across centers in the United States, with initial programmatic outcomes demonstrating promise as a both efficacious and cost-effective method for addressing ongoing donor shortages, improving utilization rates of available organs, and achieving outcomes similar to other accepted procurement methods (2,3,11-13). Additionally, while TA-NRP centers have described procurement techniques and basic equipment and logistic considerations (4,12,14), descriptions of programmatic lessons and system considerations prior to implementation of a TA-NRP program are lacking.

To improve organ utilization within our region, the University of Colorado Hospital (UCH) developed a strategy to implement a TA-NRP program for DCD heart and lung procurement. The aim of this manuscript is to characterize the UCH's experience during implementation of a TA-NRP procurement program, focusing on defining essential human resources, lessons, and key considerations needed to improve TA-NRP dissemination and thus adoption.

Methods

Study design

Single-center evaluation of a TA-NRP program was conducted using a retrospective cohort study design. All procurements performed using TA-NRP were included. Quantitative data were retrospectively collected and maintained in an internal database. Descriptive elements of programmatic genesis, implementation, and experience were summarized using an inductive reasoning approach. The University of Colorado Institutional Review Board approved data collection and research for the TA-NRP program.

Statistical analysis

Quantitative data organization and transformations were performed using RStudio version 2023.12.1.402 {Posit team [2024]. RStudio: Integrated Development Environment for R. Posit Software, PBC, Boston, MA, USA. Available at: http://www.posit.co/}. We descriptively characterized patients in the overall sample. For parametric data, we reported mean and standard deviation (SD) and for non-parametric data we reported median and interquartile range (IQR). Categorical variables were reported as numbers and percentages. Simple, unadjusted linear regression models were calculated for total TA-NRP and incision to NRP initiation times, reporting regression coefficients and 95% confidence interval (CI), and defining a P value of 0.05 as statistical significance. Figures were produced using GraphPad Prism 10.1.1 for Mac (GraphPad Software, Inc., San Diego, CA, USA).

Results

Programmatic overview and donor selection

UCH is a 678-bed quaternary care hospital located on the Anschutz Medical Campus in Aurora, Colorado. The heart and lung transplant programs have been in existence since 1986 and 1991, respectively, with postoperative care performed in the 17-bed cardiothoracic intensive care unit (CTICU) alongside the respective multidisciplinary transplant, heart failure, and pulmonology teams. Existing infrastructure was utilized for the development of a TA-NRP program, noting that some prior experience with DCD procurement was advantageous during implementation due to familiarity with preexisting and accepted techniques and procedure.

The UCH TA-NRP program was officially operationalized in October 2022. Patient selection was guided based on the International Society for Heart and Lung Transplantation (ISHLT) donor heart and lung procurement consensus

Table 1 Baseline characteristics of thoracoabdominal normothermic regional perfusion donors

Characteristic	Value (N=30)
Age (years)	32±8
Sex	
Female	8 [27]
Male	22 [73]
Race/ethnicity	
Asian	1 [3]
Black or African American	2 [7]
Hispanic or Latino	5 [17]
White	22 [73]
BMI (kg/m^2)	29±7
Progression to cardiac death	30 [100]
Donor cause of death	
Anoxia	14 [47]
Cerebrovascular/stroke	6 [20]
Other	1 [3]
Stroke	9 [30]
HCV NAT positive	2 [7]

Data are presented as mean ± SD or n [%]. BMI, body mass index; HCV, hepatitis C virus; NAT, nucleic acid test; SD, standard deviation.

Table 2 Characterization of thoracoabdominal normothermic regional perfusion program metrics

Characteristic	Value (N=30)
Donor distance (nautical miles)	12.0 [7.0–41.0]
Organs recovered	
Heart (valves or transplant)	25 [83]
Left kidney	29 [97]
Right kidney	29 [97]
Liver	20 [67]
Left lung	12 [40]
Right lung	12 [40]
Pancreas	0
Incision to NRP (min)	7±2
Total time on NRP/CPB (min)	87±28

Data are presented as median [IQR], n [%], or mean ± SD. NRP, normothermic regional perfusion; CPB, cardiopulmonary bypass; min, minutes; IQR, interquartile range; SD, standard deviation.

statement, with emphasis placed on multidisciplinary discussion with all members of the transplantation team in order to prevent exclusion of any DCD heart or lung(s) (15). More specific donor evaluation and pre-donation management specific to whether heart, lung, or both thoracic organs were to be procured for transplantation have been previously described and remain unchanged in current protocol (2,3).

Donor and TA-NRP characteristics

Based on this selection criteria, a total of 30 TA-NRP procurements were performed, with baseline donor, program and TA-NRP characteristics defined in *Tables 1*,*2*, respectively. The average donor was 32±8 years of age, with a preponderance of male sex (n=22, 73%) and white race/ethnicity (n=22, 73%). The main causes of donor death were anoxia (n=14, 47%) and of cerebrovascular etiology/stroke (n=6, 20%). The median distance to the procurement center was 12.0 (IQR, 7.0–41.0) nautical miles, utilizing both ground and air transport methods. The average number of TA-NRP procurements adjusted for the duration of the program are shown in *Figure 1*, with the average number of procurements performed per month increasing by a factor of approximately one over the course of a year.

Donors who progressed to cardiac death were included (n=30, 100%). The average time from incision to TA-NRP initiation [functional warm ischemia time (FWIT)] was 7±2 minutes and total time on TA-NRP was 87±28 minutes. Average times during program growth and increasing center experience are depicted in *Figure 2*. In simple regression analysis, the average total TA-NRP time was noted to increase by approximately 0.86 minutes per procurement (95% CI: −0.10, 1.82, P=0.08), while the average FWIT was noted to decrease by approximately 0.03 minutes per procurement (95% CI: −0.13, 0.07, P=0.43).

TA-NRP program planning: stakeholders and financial considerations

During initial program genesis, the identification of key stakeholders to facilitate both future operationalization as well as navigation of financial considerations that

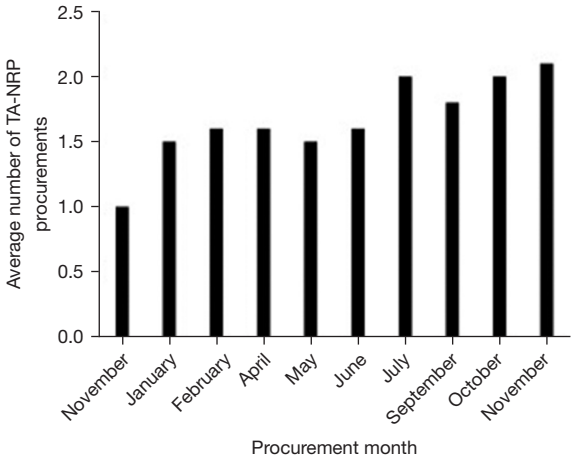

Figure 1 Average number of thoracoabdominal normothermic regional perfusion procurements performed adjusted for program duration. TA-NRP, thoracoabdominal normothermic regional perfusion.

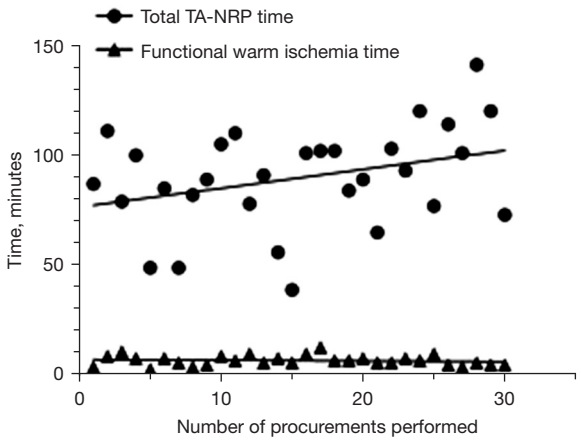

Figure 2 Trend of functional warm ischemia time and total thoracoabdominal normothermic regional perfusion time per procurement performed. TA-NRP, thoracoabdominal normothermic regional perfusion.

Table 3 Program planning: key stakeholders and considerations

Stakeholder	Considerations
Cardiothoracic surgeon team	Prerequisite is having a two-member team
Abdominal surgeon team	Education of outside network donor teams
Perfusion	Early on two perfusionists is helpful
	Develop staffing model
	ECMO specialist not advantageous due to equipment differences
Multidisciplinary team	Composed of both critical care, transplant, and respective heart and lung failure teams
	No changes to normal postoperative care
Organ procurement organizations	Key to create partnerships
	Education on protocol and equipment needs
Hospital administration	Program has implications for all organ transplantation teams
	Expectation setting around dry runs
	Growth goals

ECMO, extracorporeal membrane oxygenation.

ultimately influence administrative approval remain key steps in implementation planning (*Table 3*). One of the biggest changes centers can anticipate is expansion of the procurement team, as two members of the cardiothoracic surgery team are now required and two perfusionists are advantageous, especially in early TA-NRP cases. Given the time factor associated with rapid TA-NRP initiation, an additional perfusionist was found to allow for distribution of tasks, with a designated primary role being solely responsible for running the circuit and the second for supportive tasks that included labs, disposables, and other miscellaneous duties to ensure timeliness of both procurement but also egress from the donor facility to prevent transportation delays. As staff became familiarized

Table 4 Program planning: key logistic considerations

Characteristic	Consideration
Geographic	Local *vs.* regional
Personnel	Expanded cardiothoracic team
	Two surgeons
	Two perfusionists
	Abdominal team may require separate transport
Equipment	Influence of vehicle size
	Circuit and component transport
	Additional medication and perfusion supplies
	Communication capability if in flight

with TA-NRP procurement, our system has exchanged having a second perfusionist for a "perfusion assistant", who continues in this support role but alleviates staffing constraints. A perfusion assistant was defined as any nurse, respiratory therapist, or other allied health professional that underwent internal training to learn skills and knowledge necessary to provide perfusion support.

Perhaps the most understated change that can be anticipated is the need to interface with both abdominal surgeons and operating room staff from outside institutions. Time upon arrival must be allotted to allow for adequate education on expected workflow, equipment needs, and protocol changes from standard DCD procurements. In addition, it is essential to create strong partnerships with organ procurement organizations (OPOs), as they will augment both education and operationalization of TA-NRP, noting that failure of obtaining OPO support will result in ineffective implementation efforts. Lastly, when seeking approval from hospital administration, it is imperative that organizations acknowledge that TA-NRP is not an individual effort or an individual department's program, but one that spans across the entire organization. While critical care, heart and lung failure physicians, and all other ancillary staff are not required to make any changes to typical postoperative care and workflow, their approval and inclusion during planning promotes adoption. Lastly, while approaching administration to seek approval, it is imperative to both set expectations around dry runs and define the growth potential of the program. The UCH cardiothoracic surgery team had discussions with our OPO about increasing reimbursements, which our center found should be increased to at least 1.5× the standard rate due to the increase in complexity and required personnel, as well as to support the longitudinal growth of the program. In addition, utilization of TA-NRP may allow for transplantation of organs that otherwise would have been discarded, which is of financial benefit to the OPO. Centers should specifically discuss both local and national growth potentials with their local OPO in order to be realistic about future growth and revenue.

TA-NRP program planning: logistics

The size of the TA-NRP team remains a crucial consideration for program logistics, as it has several noteworthy considerations that influence implementation success (*Table 4*). Initially, our center anticipated at least five personnel per run: two surgeons, two perfusionists, and one preservationist. The role of the preservationist is mainly to coordinate logistics, help with equipment transportation, and facilitate communication and education between the primary procuring team, teams from other institutions, and donor hospitals. Preservationists can be either provided by the OPO or the transplant center depending on local center-specific staffing and donor systems.

This necessitated separate transportation for an abdominal procurement team from our center, as prior experience with combined transportation was not feasible simply due to limited physical space. Our center found it advantageous to start locally during initial TA-NRP initiation, which allowed for tailoring of the donor selection strategy from familiar DCD protocols, thus allowing all team members to gain familiarity with the TA-NRP process. This translated to minimization and amelioration of unanticipated issues or logistic challenges, as team members remained in familiar environments where resources could easily be obtained.

There were several important lessons noted for ground *vs.* aeromedical transport. Historically for ground transportation, a single, large vehicle would be sufficient for both team members, equipment, and coolers. Due to the expanded need of personnel and equipment, our center found that either two vehicles or a single, large sprinter-style van were optimal. Lastly, for some transports, an ambulance was utilized, noting that the stretcher had to be removed and only one ambulance staff could remain with the vehicle to accommodate the additional equipment and procurement team members. During aeromedical transport, our center asked for the largest plane available, typically with an eight-seat capacity. Key considerations were that the circuit required its own chair in addition to storage

Table 5 Thoracoabdominal normothermic regional perfusion: program checklist

Program phase	Consideration
Planning	1. Early identification of pre-existing and new stakeholders
	a. Frequent meetings
	b. Engagement of bioethics team
	2. Organ procurement organization
	a. Growth potential
	b. Necessary equipment
	c. Procurement algorithms
	3. Staffing
	a. Call schedule
	b. Hiring
	c. Time for onboarding and training
Implementation	1. Donor location
	2. Transport considerations
	3. Organ procurement organization role in donor facility education

for two bags of NRP equipment and medications. Teams should also plan accordingly based on the allografts, as additional space is required when both heart and lungs were procured. Lastly, our team found it advantageous to acquire aeromedical transport with connectivity, which improved communication with teams at both donor and home institutions. This was imperative as the increased complexity associated with TA-NRP translated to an increased need for communication, especially early on to prevent unnecessary procurement delays.

Discussion

TA-NRP has emerged as an innovative approach to reduce organ waitlist-associated mortality and address many of the historical concerns regarding organ donation after DCD; however, ethical concerns and regulatory limitations have hindered widespread adoption, and thus, description of center experiences during TA-NRP program planning, development, and implementation are lacking (4-10). Given this literature gap, the primary aim of this manuscript was to characterize our center experience during genesis and implementation of a TA-NRP program, focusing on defining essential human resources, lessons, and key considerations in order to facilitate dissemination of experience and promote widespread adoption of TA-NRP. Given this aim, we created a TA-NRP checklist (*Table 5*) to communicate key steps and lessons learned during from our institutional experience.

While many centers may be performing procurements regularly, TA-NRP required both the identification and engagement of pre-existing and new stakeholders, as well as acquisition of additional staffing. Key pre-existing stakeholders were the OPO, transplant center administration, abdominal and cardiothoracic surgeons, and all other nursing, anesthesia, intensivist, and perfusion staff. While many of these stakeholders were not directly affected by operationalization of a TA-NRP program, early inclusion promoted adoption and created system-wide cooperativity. A well-documented barrier to implementation is navigation of ethical concerns. In a study by Wall *et al.*, two ethical objections that should be discussed during initial stakeholder engagement are that NRP negates circulatory death and that NRP is inconsistent with the Dead Donor Rule (16). Our center chose to proactively include bioethicists during initial conversations around TA-NRP in order to promote discussions and address ethical objections. This was felt to improve communication amongst all stakeholders, addressed early ethical concerns, and improved institutional support across both administration and providers. For programs considering TA-NRP, early inclusion of a bioethicist is a key consideration to promote adoption and was not found to introduce delays in either program planning or implementation.

During initial planning, our center had monthly meetings with all stakeholders to discuss system-wide implications, staffing models, quantify additional staff necessary to inform hiring needs, and review necessary equipment and supplies. Early engagement of the OPO was instrumental in defining growth potentials and facilitated discussions on budget proposals with hospital administration, who then provided the necessary administrative support for obtaining additional staff and equipment. Additionally, the OPO was instrumental in the planning and coordination of system-level logistics, specifically through generation of formal equipment lists, operative note templates, pre-donation algorithms, education of outside network teams and operating room staff, and coordination of all intra- and post-donation processes. As implementation approached, these meetings were increased in frequency to bimonthly and then weekly, which were continued during initial

implementation and then deescalated to monthly. TA-NRP is a system-level program, requiring coordination of multiple departments and increased logistic considerations; therefore, early creation of a TA-NRP team with frequent, scheduled meetings is imperative. Key lessons were that, in addition to the expansion of the surgical team, two perfusionists were found to be advantageous, especially during initial implementation efforts. While extracorporeal membrane oxygenation (ECMO) specialists were qualified and capable of TA-NRP circuit management, perfusionists were found to be more efficacious due to an increased familiarity with circuit assembly and required intraoperative workflow. Given this, centers not only need to account for increased personnel, but also account for call requirements and staffing models to not disrupt pre-existing workflow or cause inadvertent staffing shortages. Hence, we found that early development of staffing models facilitated budget proposals, which, once approved, required at least six months for staff recruitment and training. Centers without pre-existing infrastructure should plan for one or two years prior to TA-NRP operationalization.

During initial implementation, the majority of TA-NRP procurements were performed in locoregional facilities, with an average distance to the donation facility of 38 miles. The predominant organs procured were both heart (83%) and kidneys (97%); however, a majority of procurements also included liver (67%) and lungs (40%). Interestingly, as TA-NRP procurement volumes increased over the course of the program duration, there was a slight increase in the average total NRP time by approximately 0.86 minutes, as well as a decrease in the FWIT time by approximately 0.03 minutes. While there was a small degree of a learning curve associated with implementation of TA-NRP, we found that our team performance was largely dictated by other procurement teams, specifically the procuring abdominal teams. This highlights that procurement times will largely be dictated by other teams and the respective abdominal organs procured, noting that communication and education around TA-NRP practices are essential to success and have implications on total duration of time spent within the donor center.

Lastly, as programs begin to implement and therefore establish their programs, an often overlooked but necessary step is formalization of an internal TA-NRP database with dedicated personnel to record relevant information. Our team had a designated member responsible for the record of all procedural times, labs, baseline characteristics of both donor and recipients, and postoperative outcomes. Curation of such databases are essential to ensuring the delivery of quality care and have implications for both future research and donor management.

Conclusions

Development of a TA-NRP program is both feasible and easily implemented at institutions with pre-existing DCD procurement experience. Early identification of key stakeholders with frequent communication identified areas in need of expanded resources and addressed early ethical concerns, while local implementation efforts supported operationalization of existing infrastructure for TA-NRP procurements.

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Footnote

Conflicts of Interest: The authors have no conflicts of interest to declare.

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