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SPECIAL REPORT

Consensus Statement: Technical Standards for Thoracoabdominal Normothermic Regional Perfusion

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ABSTRACT

BACKGROUND Thoracoabdominal normothermic regional perfusion (TA-NRP) has emerged as a powerful technique for optimizing organ procurement from donation after circulatory death donors. Despite its rapid adoption, standardized guidelines for TA-NRP implementation are lacking, prompting the need for consensus recommendations to ensure safe and effective utilization of this technique.

METHODS A working group composed of members from The American Society of Transplant Surgeons, The International Society of Heart and Lung Transplantation, The Society of Thoracic Surgeons, and The American Association for Thoracic Surgery was convened to develop technical guidelines for TA-NRP. The group systematically reviewed existing literature, consensus statements, and expert opinions to identify key areas requiring standardization, including predonation evaluation, intraoperative management, postdonation procedures, and future research directions.

RESULTS The working group formulated recommendations encompassing donor evaluation and selection criteria, premortem testing and therapeutic interventions, communication protocols, and procedural guidelines for TA-NRP implementation. These recommendations aim to facilitate coordination among transplant teams, minimize variability in practice, and promote transparency and accountability throughout the TA-NRP process.

CONCLUSIONS The consensus guidelines presented herein serve as a comprehensive framework for the successful and ethical implementation of TA-NRP programs in organ procurement from donation after circulatory death donors. By providing standardized recommendations and addressing areas of

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uncertainty, these guidelines aim to enhance the quality, safety, and efficiency of TA-NRP procedures, ultimately contributing to improved outcomes for transplant recipients.

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INTRODUCTION

Thoracoabdominal normothermic regional perfusion (TA-NRP) has been recognized as a valuable technique to optimize the procurement of both thoracic[1-12] and abdominal[13-15] organs in donation after circulatory death (DCD). Given the rapid adoption and acceptance of this technique, the American Society of Transplant Surgeons (ASTS) has convened a working group comprising members from The International Society for Heart and Lung Transplantation (ISHLT), The Society of Thoracic Surgeons (STS), and The American Association for Thoracic Surgery (AATS) to establish technical guidelines to ensure successful and ethical implementation of a TA-NRP program. The TA-NRP guidelines serve to unify recommendations and resolve areas of uncertainty on issues related to the NRP technique. The following standards and recommendations aim to provide guidance on contemporary issues involving the use of the TA-NRP technique during DCD organ procurement.

METHODS

A working group composed of members of ASTS, ISHLT, STS, and AATS with expertise in the TA-NRP technique and DCD procurement was assembled. The final recommendations were approved by the members of the working group as well as the respective ASTS, ISHLT, STS, and AATS committees. The following topics were identified by the group as needing standardization: (1) predonation period, (2) intraoperative period, (3) postdonation period, and (4) future directions/areas of research. A summary of the salient recommendations from the TA-NRP technical standards working group is found in Table 1.

PREDONATION PERIOD. Thoracoabdominal NRP is a complex procedure requiring collaboration between many members of the transplant community. Because of the logistic complexity of the NRP procedure, the following recommendations are suggested to help facilitate successful coordination during the predonation period.

Recommendations

1. Donor evaluation and selection: Evaluation and selection of DCD donors should be similar to that of donors after brain death. As the potential for premortem testing of the DCD donor evolves, the use of “expanded criteria” DCD donors may also evolve.
2. Premortem testing and therapeutic interventions: Recognizing the balance between patient care and the importance of a patient and family’s desire for organ donation, premortem testing and therapeutic interventions that maximize a patient’s potential for organ donation should be permitted. As the use of expanded criteria donors in both heart and lung transplantations continues to evolve, premortem testing and medication administration may facilitate thoracic organ donation while limiting the organ discard rate. Limitations to predonation testing and intervention may preclude organ acceptance and should be acknowledged in the donation process.
3. Recognizing heterogeneity in organ procurement organization (OPO) policy and procedure, consideration should be given to full transparency in discussions regarding the planned method of organ procurement with donor family or designated decision makers before donation.
4. Prediction of death after withdrawal of life-sustaining treatment (WLST): Identification of a patient’s chance of progression to death after WLST within a prespecified time poses unique challenges to the procurement team. Several tools have been developed to predict the likelihood of asystole and circulatory death after WLST.
   a. Use of existing prediction models is recommended to maximize the chance of successful organ recovery (Table 2).[17,18,20-22]

TABLE 1 Summary of Key Recommendations From TA-NRP Technical Standards Working Group

Time Period	Recommendation
Predonation	1. Evaluation and selection of DCD donors should be similar to that of donors after brain death. 2. Premortem testing and therapeutic interventions that maximize a patient's ability for organ donation should be permitted. Premortem testing and medication administration may facilitate thoracic organ donation while limiting the organ discard rate. a. Premortem testing and therapeutic interventions may include venipuncture for predonation laboratory testing, predonation medication administration, CXR, CT scan, therapeutic bronchoscopy with BAL, donor prone positioning, ventilatory recruitment maneuvers, lung protective ventilation, right heart catheterization, coronary angiogram, and transthoracic or transesophageal echocardiogram. 3. Discussions with the patient's family or a patient's designated decision makers regarding the planned method of donor organ procurement should be instituted before donation. 4. Sharing of existing protocols and equipment checklists is encouraged to ensure that all members of the procurement and transplant team understand the NRP process before arrival at the donor hospital. 5. DCD donor monitoring should include (1) arterial hemodynamic monitoring and (2) peripheral or central intravenous access for medication administration and laboratory measurement. a. Arterial or venous access in the neck or upper extremity may fail after initiation of TA-NRP. b. Essential monitoring devices (pulse oximeter, intra-arterial blood pressure line) and intravenous catheters should preferentially be placed in the lower extremities to avoid malfunction after cerebral vessel ligation or division of the innominate vein before initiation of TA-NRP. 6. Team communication is essential for a smooth TA-NRP organ recovery. A preprocurement team brief is recommended (1) before arrival at the donor hospital, (2) before WLST. 7. An intravenous heparin bolus of at least 400 units/kg should be administered at least 3 min before WLST. 8. WLST should occur in a location predetermined by the hospital or OPO policy after consultation with the family. 9. Complete separation between the patient care and procurement teams should be maintained at all times before the physical act of allograft procurement. 10. Patient family or caregivers should be given the option of being present during WLST through the period of declaration of death. 11. A period of at least 120 min after WLST is recommended to maximize the possibility of successful multiorgan donation. 12. A period of no <5 min of "no-touch" should be observed before the start of DCD organ procurement.
Intraoperative	1. Standard of care during TA-NRP requires prevention of cerebral flow before initiation of systemic perfusion with TA-NRP. 2. Any method that ensures adequate ligation of all brachiocephalic vessels is recognized as being acceptable for cerebral vessel management before the institution of TA-NRP flow. a. Ligation of the brachiocephalic vessels with a single vascular clamp is not recommended because of the risk of inadvertent clamp dislodgement during the TA-NRP procedure. 3. The abdominal and thoracic surgical teams should delineate cannulation strategy, timeline, and contingency plans before WLST. 4. Tracheal reintubation should be performed by a board-certified anesthesiologist or their delegate and this role should be assigned before WLST. 5. The optimal TA-NRP duration has not yet been defined. If a thoracic-only recovery is being performed, strong consideration should be given to limiting TA-NRP duration to <60 min.
Postdonation	1. Documentation by the OPO should be completed and uploaded as part of the donor's medical record in a timely manner. 2. Documentation by the procuring surgical teams should be completed and uploaded as part of the donor's medical record in a timely manner. 3. When drafting documents for clinical, legal, or research purposes, terminology such as "reanimation," "resuscitation," "circulation," and "extracorporeal membrane oxygenation (ECMO)" should be avoided when describing the NRP technique and the DCD process.
Future directions/ areas of research	1. Recommendations are made to promote continued investigation to further clarify areas of uncertainty. 2. Addition to the DDR to include the procurement technique used during DCD organ recovery is strongly recommended to allow for future analysis of the NRP recovery technique. 3. During WLST, participation of providers with specialized training in symptom palliation and end-of-life care is strongly recommended. 4. A formal process for privileging and credentialing teams performing TA-NRP should be established by each hospital and OPO using TA-NRP for DCD organ donation. The credentialing process should be formally documented and follow 1 of 2 pathways (see the text for details). 5. Institutions with established TA-NRP programs should promote transparency and accountability by partnering with and providing mentorship to transplant centers interested in starting a TA-NRP program at their institution. 6. Institutions with NRP programs should engage in ongoing monitoring of quality and continued programmatic improvement by partnering with their respective transplant center service line as well as the institution's clinical excellence and patient safety departments. 7. Development and use of a national centralized database containing donor and recipient characteristics and outcomes should be established for quality improvement, self-assessment, and research purposes.

BAL, bronchoalveolar lavage; CT, computed tomography; CXR, chest x-ray; DCD, donation after circulatory death; DDR, Deceased Donor Registry; OPO, organ procurement organization; TA-NRP, thoracoabdominal normothermic regional perfusion; WLST, withdrawal of life-sustaining treatment.

TABLE 2 Summary of Clinical Models Used to Predict Death in DCD Donors

	Pro	Con
United Network for Organ Sharing criteria[16]	• Prospectively validated in a large cohort • Uses readily available clinical data	• Limited criteria included on donor neurological status (Glasgow coma scale only) • Predicts donor death only up to 60 min • Predicts death but does not predict the success of recovering a suitable organ
University of Colorado DCD Progression Calculator[17]	• Uses readily available patient data (age, cause of death, reflexes, CBC/BMP, etc)	• Methodology not currently published for peer review • Not prospectively validated • Does not predict death beyond 30 min after withdrawal of life-sustaining treatment • Predicts death but does not predict the success of recovering a suitable organ
University of Wisconsin DCD Evaluation Tool[18]	• Predicts death suitably up to 120 min • Uses easily accessible patient data (BMI, vitals, age, oxygen saturation)	• Limited criteria included on donor neurological status • Not prospectively validated • Predicts death but does not predict the success of recovering a suitable organ. • Score developed using limited sample size (n = 43)
Chinese DCD Nomogram[19]	• High degree of predictive accuracy at 30, 60, 120, and 240 min • Validated in a prospective, multicenter study. • Allows for prediction of death at >120-min intervals	• Requires detailed neurologic evaluation (reflexes, response to pain, pupillary size). • Relies on more detailed radiographic metrics (evaluation for swirl sign and width of cisterna ambiens on head CT) • Validated in a selected neurocritical patient cohort • Has not been validated in the international population • Predicts death but does not predict the success of recovering a suitable organ

BMI, body mass index; BMP, basic metabolic panel; CBC, complete blood count; CT, computed tomography; DCD, donation after circulatory death.

b. Consideration can be given to the involvement of consultants, such as the neurology or neurocritical care service, to further stratify the likelihood of a patient's progression to death after WLST.

5. Equipment checklists: Preprinted checklists facilitate a smooth procurement process. Sharing of existing protocols and equipment checklists in the predonation phase is encouraged to ensure that all members of the procurement and transplant team understand the NRP process *before* arrival at the donor hospital (Table 3).

6. Patient monitoring and intravenous access: Monitoring of the patient's vital signs and ability to administer medication is of critical importance after WLST. At a minimum, donor monitoring should include (1) arterial hemodynamic monitoring and (2) peripheral or central intravenous access for medication administration and laboratory measurement.

   a. Arterial or venous access in the neck or upper extremity will cease to function after occlusion of the aortic arch branch vessels immediately before the initiation of TA-NRP.

   b. After initiation of TA-NRP, if intravenous access is limited, medication can be given directly into the TA-NRP circuit.

   c. After initiation of TA-NRP, if peripheral intra-arterial monitoring is unreliable, central aortic pressure can be transduced from a catheter placed into the ascending aorta.

7. Preprocurement communication: Team communication is essential for a smooth TA-NRP organ recovery. A preprocurement team briefing is recommended at 2 time points:

   a. A "virtual" team briefing is recommended before the departure of the procurement team from their transplant center. This team brief should include procurement and transplant surgeons, OPO representatives and coordinators, and perfusion team members.

      i. The virtual team brief is an opportunity for organ procurement teams to discuss variations in procurement techniques and work collaboratively to develop a procurement strategy that maximizes the possibility of a successful recovery.

TABLE 3 Example of an Instrument Checklist Used During an NRP Procurement to Ensure Availability of Surgical Tools Before Arrival to the Donor Hospital

TA-NRP Instrument Checklist
Surgical drapes
Additional surgical drape to be used for nonsterile procedures (chest auscultation), if necessary
No. 10 blade × 2 (with a single handle for each blade)
No. 11 blade × 2 (with a single handle for each blade)
Electrocautery device × 1 (connected and tested)
Sternal saw with backup batteries (connected and tested before procedure)
Lebsche sternum knife (as backup, if necessary)
Internal cardiac defibrillator device
External cardiac defibrillator pads
Handheld retractors × 2
Forceps × 3
Heavy scissors (to divide lines)
Fine scissors (for fine dissection)
30-mL syringe and 3-way stopcock for de-airing of NRP lines
4-0 prolene with RB or SH needle × 6
Rummel tourniquets × 4
Instrument holder × 2 (to be placed on the surgeon and assistant side)
Hemostats × 6
High-pressure arterial line tubing (to monitor central pressure if necessary)
Aortic cross-clamp
Angled or straight clamps × 3 (for cerebral vessel management)
Sternal retractor (assembled and tested before use)
Tubing clamps (for NRP circuit tubing management)
NRP cannulas: venous drain via RA, arterial return via ascending aorta, optional pulmonary artery vent, left atrial or left ventricular vent, cardiotomy suction as needed, and "root" vent/cardioplegia delivery cannula
4 units of packed red blood cells were cross-matched and checked the start of the TA-NRP procedure

NRP, normothermic regional perfusion; RA, return via ascending aorta; RB, renal (artery) bypass; SH, small half (circle); TA-NRP, thoracoabdominal NRP.

b. An "onsite" team brief should take place after the arrival of all participating teams. This team brief should include procurement surgeons, OPO representatives and coordinators, and perfusion team members.
c. Preprocurement communication should define the role of the abdominal and thoracic teams as well as the sequence of events. Essential communication should include timing and method of cerebral vessel exclusion, timing and dose of pre-WLST heparin, confirmation of the presence of at least 4 units of prechecked, cross-matched banked blood, method of NRP cannulation, duration of the NRP run, contingency plans for a failed NRP run, and plan for reintubation and ventilator management.
   i. During the predonation huddle, the team responsible for performing TA-NRP should confirm their commitment to proceeding with cannulation and perfusion of the donor for the benefit of other teams, even if the time from WLST to death exceeds their predetermined acceptable threshold.
d. The preprocurement team brief should also be used to identify the following team member responsibilities: declaration of death, donor transport (if WLST occurs outside of the operating room), donor positioning, donor preparation and draping, equipment management (electrocautery, suction devices, and internal and external defibrillator pads), donor reintubation, withdrawal timeline and NRP record keeping, surgical assistant, and NRP circuit initiation and maintenance.

8. WLST period: Variability exists in the phase of care around WLST. To preserve public trust and to standardize the practice of DCD donation, the following recommendations are made:
   a. An intravenous heparin bolus of at least 400 units/kg should be administered at least 3 min *before* WLST.
   b. WLST should occur in a location predetermined by the hospital or OPO policy after consultation with the family.[23]
   c. Complete separation between the patient, their family or designated decision maker, the team performing WLST, and procurement teams should be maintained before the physical act of organ procurement.
   d. The provider(s) involved in WLST should be designated in the preprocurement team brief. The provider(s) involved in WLST should be a physician, or their designer, and *must* be knowledgeable in end-of-life care protocols and symptom palliation.
      i. Physicians or physician delegates, including nurses or other qualified anesthesia providers, are authorized to perform WLST, end-of-life palliation, and declaration of death under certain circumstances as determined by state and local law and hospital policy. Providers designated for this purpose should be identified in the preprocurement team brief.
   e. The provider(s) responsible for WLST should not include members of the thoracic or abdominal recovery team or members of the OPO.
   f. The period from WLST to mandatory termination of the procurement procedure is highly variable and dependent on discussions between local OPO and hospitals. A period of

at least 120 min after WLST is recommended to maximize the possibility of successful multiorgan donation.

g. The physiologic conditions that define the "agonal period" vary by organ. Currently, there is no consensus on the hemodynamic parameters that define the "agonal period" in heart or lung donation. Experience suggests that systemic oxygen saturation may be misleading in the perimortem period and may not be accurate for defining the "agonal period." Therefore, preference should be given to the in situ function and physiology of the donor organ when making decisions regarding the acceptance of a donor heart or lung for transplantation.

h. A "stand-off" or "no-touch" period should be observed after asystole. Once this period concludes, cardiocirculatory death should be declared by a predesignated provider.
   i. Evidence on "autoresuscitation" is limited. Transient resumption of cardiac activity after pulselessness is not sufficient to support the physiologic needs of a patient in the perimortem period. However, a period of no <5 min of "no-touch" should be observed before the start of DCD organ procurement[24,25]
   ii. Efforts to initiate TA-NRP expeditiously should be prioritized after the declaration of death. Current evidence suggests that initiation of TA-NRP within 10 min of circulatory arrest is not associated with significant detriment to cardiomyocyte function or viability.[26]

i. Recommendations for involvement of physicians trained in anesthetic management and palliation at the end of life are consistent with guidance from The American Society of Anesthesiologists Statement on Controlled Organ Donation After Circulatory Death. Portions of the American Society of Anesthesiologists guidelines related to the Anesthesiologist's role in the DCD process are reprinted below[27]:
   i. "Provision of quality end-of-life care for DCD patients and their families is the absolute priority and must not be compromised by the donation process."
   ii. "While anesthesiologists staffing operating rooms should not be required to participate in withdrawal of care or declaration of death, they may be asked to reintubate and ventilate lungs to support and facilitate the DCD process, or to be engaged in postmortem circulatory support in NRP. Either role would also preclude their involvement in antemortem procedures supporting the donation process, which should normally occur in the ICU prior to transfer to the operating room."

INTRAOPERATIVE PERIOD. Successful recovery of thoracic organs during TA-NRP requires a thorough knowledge of the complex interaction between the heart and lungs in the perimortem period. Understanding that cannulation strategies and initiation of TA-NRP will differ by procurement team, certain basic principles must be observed during the TA-NRP period to maximize recovery of both the heart and lung allografts for transplantation.

Recommendations

1. Cerebral vessel management: Standard of care during TA-NRP requires prevention of cerebral reperfusion *before* initiation of regional perfusion with TA-NRP. In doing so, blood flow via the TA-NRP circuit is directed only to areas of the body requiring perfusion of donor organs, namely the chest and abdomen. Preclinical and clinical models have shown that ligation of the brachiocephalic vessels is effective at preventing blood flow to the brain and brainstem.[28-31] In addition, a variety of TA-NRP circuits are currently in use throughout the United States, but not all have the capacity to collect vented cerebral blood. There is currently no evidence that adjunctive cerebral monitoring during the TA-NRP period is necessary to ensure the absence of cerebral activity. Based on the availability of evidence, we strongly recommend the following strategies for cerebral vessel management in all TA-NRP cases:
   a. Care should be taken to expose and ligate the brachiocephalic vessels *before* initiation of regional flow via the TA-NRP circuit.
   b. There are multiple recognized methods for ligation of the brachiocephalic vessels. Given the limited research in this area, any method that ensures adequate ligation of all brachiocephalic vessels is recognized as being acceptable for cerebral vessel management before the institution of TA-NRP flow. Examples of techniques for cerebral vessel management are illustrated in Figure 1.

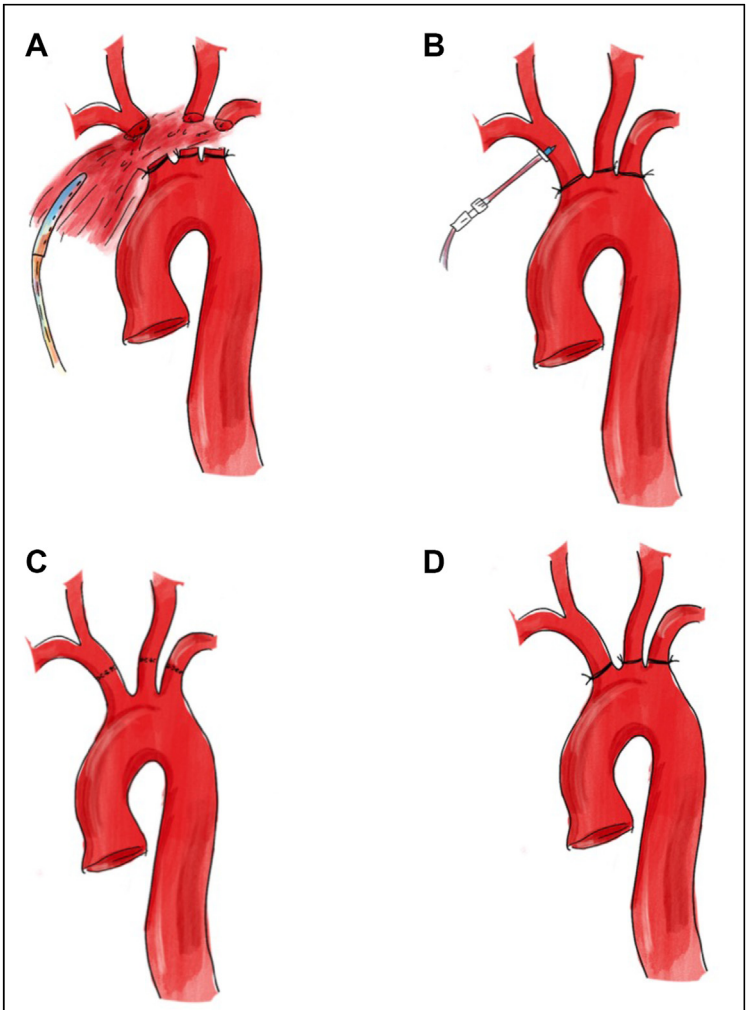

FIGURE 1 Examples of techniques for cerebral vessel management: (A) brachiocephalic vessel venting to atmosphere; (B) brachiocephalic vessel venting to normothermic regional perfusion pump; (C) ligation with vascular stapler; and (D) suture ligation.

i. Occlusion of the brachiocephalic vessels with a single vascular clamp as the sole method for cerebral vessel ligation is not recommended because of the risk of inadvertent clamp dislodgement during the TA-NRP procedure.

c. The timing and strategy of cerebral vessel ligation is an essential component of the preprocurement team brief and should be confirmed and noted appropriately before the start of WLST.

d. The timing and strategy of cerebral vessel ligation is essential to the procurement operative note and should be confirmed and noted appropriately in the operative documentation.

2. Cardiac cannulation and airway management: Thoracic organ recovery in cDCD donors must occur rapidly while also preventing damage to the thoracic or abdominal organs. Unnecessary organ loss should be avoided while recognizing the importance of adequate tissue margins during cardiectomy and pneumonectomy.

a. The abdominal and thoracic surgical teams should delineate cannulation strategy, timeline, and contingency plans *before* WLST. These discussions should include the need for simultaneous laparotomy and sternotomy, the location of TA-NRP cannula and vent placement, the timeline required for TA-NRP cannulation, and a contingency plan for the unintended failure of the TA-NRP technique.

b. Standard TA-NRP cannula placement involves a venous drainage cannula placed in the right atrium and an arterial return cannula placed into the distal ascending aorta (Figure 2). Deviations from a standard cannula placement should be discussed before WLST.

c. Placement of intracardiac vents may benefit thoracic allograft decompression.

i. Cardiac venting strategies include placement of a pulmonary artery (PA) vent (in the event of lung recovery) or placement of a left atrial (LA) or left ventricular vent for cardiac decompression.

ii. The location of cardiac vents should be coordinated with both thoracic procurement teams before WLST.

iii. After initiation of TA-NRP, the location and placement of cardiac vents should again be confirmed by the heart and lung procurement team so that both allografts receive adequate allograft tissue margins.

d. Intubation is recognized as an important aspect of lung donation.

i. Tracheal reintubation should be performed *expeditiously,* after securing drainage and return cannulas, by a board-certified anesthesiologist or their delegate, and this role should be assigned before WLST.

ii. Tracheal intubation is the preferred strategy. In the absence of a provider trained in intubation, placement of a sterile endotracheal tube can be accomplished by direct tracheal placement through the surgical field without sacrificing tracheal length on the lung allograft.

e. Lung protective ventilation with intermittent recruitment maneuvers is an important

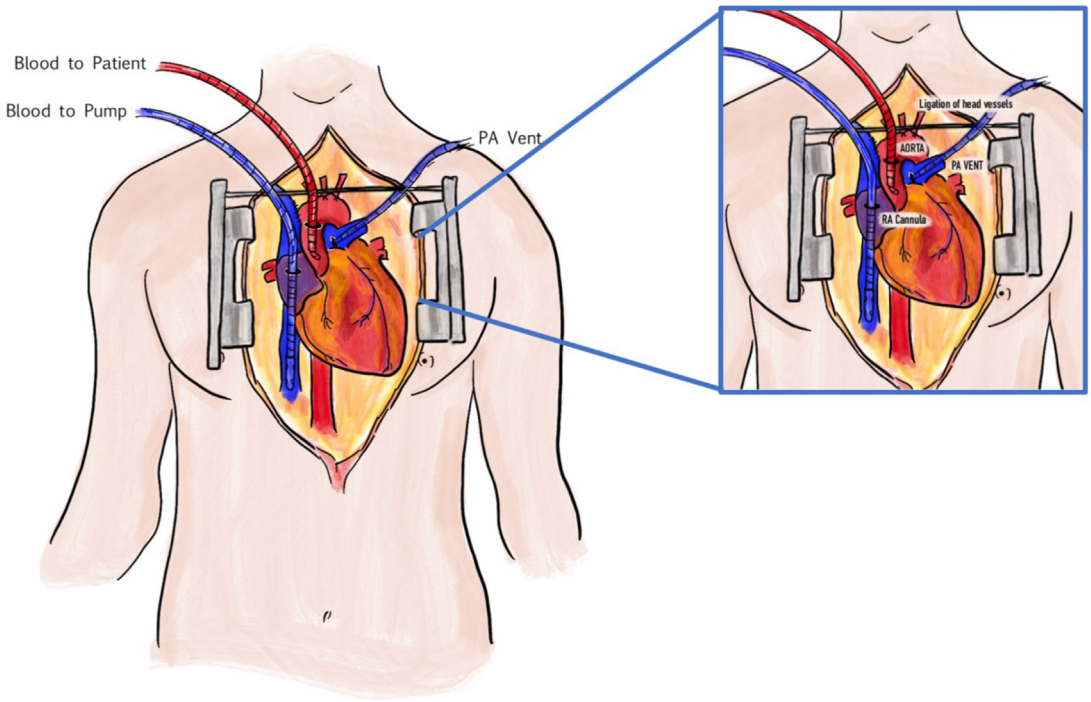

FIGURE 2 Thoracoabdominal normothermic regional perfusion cannulation strategy. (PA, pulmonary artery; RA, right atrium.)

aspect of donor lung evaluation and management. Prevention of perioperative lung injury is paramount and the use of TA-NRP for recovery should not change the basic tenets of ventilator management during lung recovery.

i. Examples of lung protective ventilatory parameters include tidal volumes of 4-8 mL/kg predicted body weight, respiratory rate of 10-15 breaths/min, positive end-expiratory pressure of 5-10 cm-H_2O based on body habitus, and fraction of inspired oxygen that is rapidly reduced after intubation to 0.4.
ii. Using "sweep" gas and oxygen delivery fraction via the circuit oxygenator, the TA-NRP circuit is used to maintain normal arterial blood gas (ABG) parameters.
iii. Intermittent recruitment maneuvers may be necessary to treat atelectasis and evaluate the donor lung before procurement.

f. The TA-NRP circuit is used to supply oxygenated blood to target end organs in the absence of pulsatile cardiac output. Essential components of a TA-NRP circuit include a reservoir, oxygenator, pump, tubing, and cannula. Examples of TA-NRP circuits are shown in Figure 3.

i. A blood flow rate indexed to donor body surface area should be maintained >2.2 L/m/m^2.
ii. Alternatively, TA-NRP goal-directed perfusion parameters can be monitored to maintain an oxygen delivery index of at least 280 mL/min/m^2.[32]
iii. Evidence for an ideal temperature management strategy during TA-NRP is lacking. A reasonable approach for temperature management during TA-NRP is to maintain normothermia to slight hypothermia (>34 °C) for the duration of the NRP process.
iv. ABG should be obtained within the first 5 min after initiating TA-NRP. The ABG should be used to guide allograft recovery, and the values should be corrected using a combination of sodium bicarbonate infusion, changes to "sweep gas" flow rates, and changes to a fraction of delivered oxygen via the TA-NRP oxygenator.

g. The optimal TA-NRP duration has not yet been defined. Loss of reservoir volume caused by prolonged donor organ dissection during the TA-NRP process will require transfusion of banked blood or additional

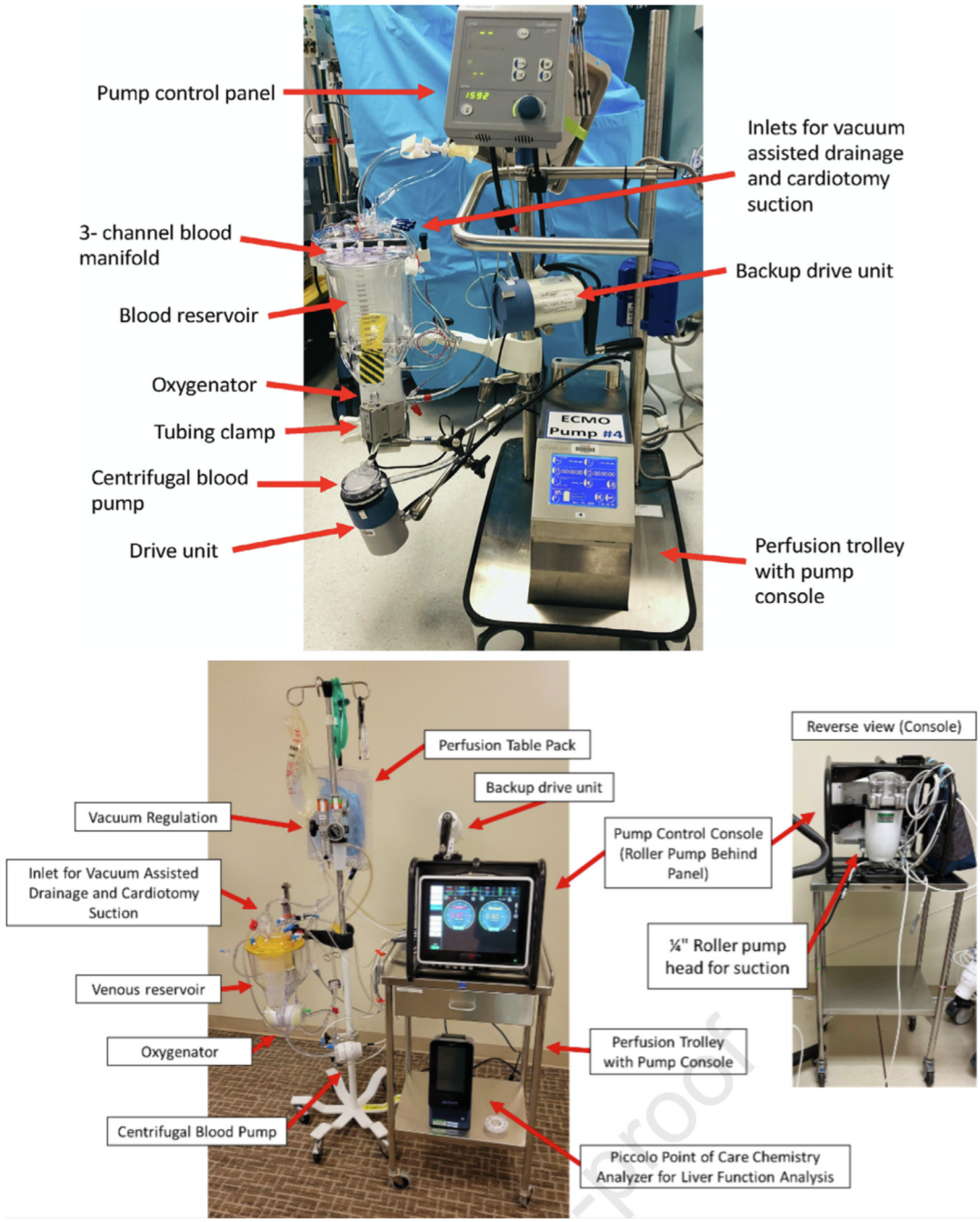

FIGURE 3 Examples of thoracoabdominal normothermic regional perfusion circuits. Reprinted with permission.[1,2]

administration of volume. Recognizing the balance between the detrimental effects on the donor heart from lack of pulsatility with the need to provide adequate systemic flow for the abdominal allografts, TA-NRP duration should be discussed and agreed on before WLST.

i. If a thoracic-only recovery is being performed, consideration should be given to limiting TA-NRP duration to <60 min. Experience has shown that this time limit reduces the need for banked blood transfusion, additional volume administration, and mitigates the detrimental effects of nonpulsatile flow

and neurogenic pulmonary edema on the heart and lung allografts.

ii. Discontinuing TA-NRP allows the resumption of native cardiac ejection with the return of pulsatile flow. If additional time is needed for donor organ dissection or trending of laboratory values, weaning and discontinuing TA-NRP with simultaneous return of reservoir volume should be considered.

3. TA-NRP can be used to safely and successfully recover donor lungs.[2,4-7] To minimize the risk of pulmonary edema in the donor lungs, several "lung protective" strategies have been proposed[2]:
   a. Aggressive predonation diuresis with intravenous loop diuretic infusion at prespecified time points to induce a "negative" donor fluid balance.
   b. Complete drainage of donor blood after placement of the right atrial venous drain. This is felt to reduce intracardiac pressures as well as venous congestion to the liver, lungs, and kidneys before the institution of TA-NRP flow.
   c. Placement of a PA, LA, or left ventricular vent to further reduce the hydrostatic pressure experienced by the lung allograft. Centers with experience in lung allograft recovery after TA-NRP suggest that preferential placement of the vent in the main PA adequately reduces LA hypertension while providing tissue cuffs to both the donor heart and lungs.[2]
   d. Early reintubation with gentle recruitment maneuvers and lung protective ventilation.
   e. Minimizing the TA-NRP interval to $<$60 min if possible. If additional time for dissection and laboratory trend is necessary, consideration can be given to weaning TA-NRP completely and allowing for the resumption of pulsatile flow.
4. In situ donor organ assessment is important to thoracic organ recovery. Tenants of donor organ inspection and assessment should not differ substantially from that of brain-dead donors.
   a. TA-NRP should be weaned to "off" to assess native cardiac contractility and function as well as adequate pulmonary gas exchange. The TA-NRP reservoir volume should be returned to the patient during this period through the arterial return cannula. Care should be taken to ensure reduced right ventricular afterload with either PA vent placement or intubation of the donor before weaning TA-NRP support. The amount of required intravenous support for the maintenance of stable hemodynamics should be noted and discussed with the implanting surgeon.
   b. Once the donor has been weaned off TA-NRP, the function and quality of the donor lungs should undergo rigorous standard evaluation. Although a reasonable assessment can be made with a reduction in sweep gas flow, a more thorough practice would include a full assessment of the lungs after the complete discontinuation of TA-NRP.
      i. To maximize the chance of a successful lung procurement, an extended period of observation of TA-NRP may be necessary. The length and timing of this assessment period should be agreed on by the other procuring teams and should be discussed before the start of the procurement.
   c. If indicated, individual pulmonary vein gas samples can be obtained as an additional means for donor lung evaluation. This should be performed after optimizing the amount of ventilator support required and weaning fully from TA-NRP support.
   d. As experience grows with TA-NRP in expanded criteria donors, the use of adjunctive testing may be necessary to complement traditional means of donor allograft evaluation. Adjunctive intraoperative testing can include
      i. Laboratory testing (ABG, lactate levels, and cardiac biomarker testing)
      ii. Therapeutic bronchoscopy with bronchoalveolar lavage
      iii. Measurement of intracardiac pressures either directly or via PA catheter
      iv. Coronary artery evaluation with angiogram
      v. Surface or transesophageal echocardiogram
5. Placement of aortic cross-clamp signifies completion of the TA-NRP donation process. As per the donation after brain death process, the donor heart and lungs are decompressed by venting to the atmosphere or into the TA-NRP circuit and then subsequently flushed with a preservation solution. Donor heart and lung dissection and procurement then proceed in the standard manner. The procured organs are either maintained with cold static storage, temperature-regulated storage, or perfused using an ex situ device during transportation.

POSTDONATION PERIOD. Record keeping and documentation are important steps in memorializing

the events of a TA-NRP case. Maintaining accurate records allows the transplant community to participate in quality improvement initiatives and more thoroughly examine results and outcomes of the donation process through scientific inquiry.

Recommendations

1. Documentation by the OPO and procuring surgical teams should be completed and uploaded as part of the donor's medical record in a timely manner. An example data collection form for a donor procurement where TA-NRP is used is included in Table 4.
2. When drafting documents for clinical, legal, or research purposes, terminology, such as "reanimation," "resuscitation," "circulation," and "extracorporeal membrane oxygenation (ECMO)" should be avoided when describing the NRP technique and the DCD process. These terms do not clearly reflect the process of organ recovery from a donor who has already been declared deceased after circulatory arrest.

FUTURE DIRECTIONS/AREAS OF RESEARCH. Excellent short-term and mid-term outcomes have been demonstrated with use of TA-NRP for thoracic and abdominal organ procurement. As with any novel technique, deficiencies in knowledge still exist. Strong recommendations are made to promote continued investigation to further clarify areas of uncertainty.

Recommendations

1. The outcomes after TA-NRP in certain populations remain unknown.
   a. Consideration should be given to research that helps understand the effects and outcomes of the TA-NRP process on donors and recipients of extreme age.
   b. Consideration should be given to research into further elucidating the effects of TA-NRP on donor physiology and donor organ function. Persistent issues of interest include
      i. the effect of normothermia versus moderate hypothermia during thoracoabdominal perfusion
      ii. further characterization of strategies to mitigate the perceived risk of donor pulmonary edema in the dying process
   c. Consideration should be given to research that helps understand the implications of continued expansion of TA-NRP programs on donation and transplantation rates in underserved or disadvantaged populations.
   d. Consideration should be given to improving research that helps understand a patient's likelihood of progression to asystole at varying time intervals. Accurate assessment tools will allow transplant centers and OPOs to minimize the rate of donor organ discard or allograft nonuse.
2. National standards for palliation and end-of-life care in DCD organ donors are lacking. During WLST, participation of providers with specialized training in symptom palliation and end-of-life care is strongly recommended.
3. Program stewardship and mentorship are important aspects of the dissemination and implementation of knowledge and technical skills.
   a. TA-NRP is a highly technical procedure requiring rapid cannulation and initiation of regional perfusion. Therefore, surgeons and perfusionists performing TA-NRP for heart and lung recovery should have experience with cannulation and initiation of mechanical circulatory support, as well as a thorough understanding of thoracic anatomy in various populations to ensure successful donor heart and lung recovery.
   b. A formal process for privileging and credentialing teams performing TA-NRP should be established by each hospital and OPO using TA-NRP for DCD organ donation. The credentialing process should be formally documented and should follow 1 of 2 pathways:
      i. Training pathway: This applies to a surgeon who has had formal training in thoracic or abdominal organ recovery using the TA-NRP procedure. A letter supporting such training must document experience (via an operative log) and competency to independently perform thoracic or abdominal organ recovery with the TA-NRP technique, with at least 5 successfully completed cases.
      ii. Experience pathway: This applies to a surgeon who has no formal training in using TA-NRP for thoracic or abdominal organ recovery. The surgeon should complete a minimum of 5 proctored thoracic or abdominal organ recoveries using the TA-NRP technique. A letter supporting such training must document experience (via an

TABLE 4 DCD Organ Assessment and Adjunctive Testing Record

1. Heart
   a. Conventional anatomy? (Y/N)
      i. If no, then comment:
   b. Normal aorta? (Y/N)
      i. If "no"
         1. Aortic hematoma
         2. Aortic dissection
         3. Aortic aneurysm
         4. Luminal atheroma
         5. Other (comment):
   c. Visual inspection/palpation normal? (Y/N)
      i. If "no"
         1. Coronary calcium
         2. PFO
         3. ASD
         4. Valve abnormality
            a. TV (comment)
            b. PV (comment)
            c. MV (comment)
            d. AV (comment)
         5. Other (comment):
      ii. Procurement injury? (Y/N)
         1. If "no" then comment:
   d. Contractility/function normal by visual inspection? (Y/N)
      i. Visual estimate of LV function on NRP (normal/abnormal), BP (MAP): / ( ) mm Hg
      ii. Visual estimate of RV function on NRP (normal/abnormal), BP (MAP): / ( ) mm Hg
      iii. Visual of LV function off NRP (normal/abnormal), BP (MAP): / ( ) mm Hg
      iv. Visual of RV function off NRP (normal/abnormal), BP (MAP): / ( ) mm Hg
   e. Adjunctive testing (if completed)
      i. Intracardiac pressures/saturations:
         1. Location of measurement: mm Hg, %, "not done"
      ii. Coronary angiogram:
         1. Coronary segment: %, bridge (Y/N), dissection (Y/N), other (comment)
      iii. Echocardiogram:
         1. Type: Epicardial, TTE, TEE
         2. RV dysfunction?
            a. Normal
            b. Abnormal (mild/moderate/severe)
         3. LV dysfunction?
            a. Normal/abnormal (LVEF: %)
            b. Global/segmental (abnormal segment:)
         4. Valves:
            a. TV: Normal/abnormal (leaflet, annular, subvalvular, vegetation, other)
            b. PV: Normal/abnormal (leaflet, annular, subvalvular, vegetation, other)
            c. MV: Normal/abnormal (leaflet, annular, subvalvular, vegetation, other)
            d. AV: Normal/abnormal (leaflet, annular, subvalvular, vegetation, other)
         5. Aorta:
            a. Normal
            b. Abnormal (aneurysm, dissection, IMH, atheroma, other)
         6. Intracardiac:
            a. Normal
            b. Abnormal: PFO/ASD/VSD/other (comment)
         7. Other findings (comment):
2. Lung
   a. Bronchoscopy
      i. Conventional endobronchial anatomy? (Y/N)
         1. If no, then comment:
         2. Tracheal bronchus/"bronchus suis"? (Y/N)
      ii. Secretions:
         1. None
         2. Thick
            a. Location: Diffuse, R side, L side, RUL, RML, RLL, LUL, lingula, LLL
            b. Reaccumulating? (Y/N)
            c. BAL? (Y/N)
         3. Thin
            a. Location: Diffuse, R side, L side, RUL, RML, RLL, LUL, lingula, LLL
            b. Reaccumulating? (Y/N)
            c. BAL? (Y/N)
         4. Pulmonary edema (Y/N)
            a. Location: Diffuse, R side, L side, RUL, RML, RLL, LUL, lingula, LLL
      iii. Foreign body: (Y/N)
         1. If yes, then comment:
      iv. Mucosa: (edematous, hyperemia, defect/location, nodule, or mass, other [please comment])
         1. If nodule/mass, was biopsy performed? (Y/N)
   b. In situ inspection
      i. Pleural space: normal/adhesions/turbid effusion/simple effusion
      ii. For each lobe (RUL, RML, RLL, LUL, lingula, LLL):
         1. Normal appearance and color? (Y/N)
            a. If "no" then comment:
            b. Anthracosis? (Y/N)
         2. Weight? Heavy/light
         3. Findings:
            a. Consolidation/infarct/nodule/mass/serosal injury or tear
               If nodule/mass, was biopsy performed? (Y/N)
            b. Atelectasis (recruitable or nonrecruitable)
            c. Procurement injury? (Y/N)
               If "no" then comment:
   c. Adjunctive testing
      i. Pulmonary vein saturations
         1. Vein location (R/L, upper/lower/other):
            a. PaO_2
            b. SaO_2 (% saturation)
         2. Systemic:
            a. PaO_2
            b. SaO_2 (% saturation)

ASD, atrial septal defect; AV, aortic valve; BAL, bronchoalveolar lavage; BP, blood pressure; DCD, donation after circulatory death; IMH, intramural hematoma; L, left; LLL, left lower lobe; LUL, left upper lobe; LV, left ventricle; LVEF, left ventricular ejection fraction; MAP, mean arterial pressure; MV, mitral valve; N, no; NRP, normothermic regional perfusion; PFO, patent foramen ovale; PV, pulmonary valve; R, right; RLL, right lower lobe; RML, right middle lobe; RUL, right upper lobe; RV, right ventricle; TEE, transesophageal echocardiogram; TTE, transthoracic echocardiogram; TV, tricuspid valve; VSD, ventricular septal defect; Y, yes.

operative log) and competency to independently perform thoracic or abdominal organ recovery with the TA-NRP technique, with at least 5 successfully completed cases.

c. Institutions with established TA-NRP programs should promote transparency and accountability by partnering with and providing mentorship to transplant centers interested in starting a TA-NRP program at their institution.

d. Institutions with NRP programs should monitor quality and continued programmatic improvement by partnering with their respective transplant center service line as well as the institution's clinical excellence and patient safety departments.

4. Donor and recipient outcomes tracking is important to programmatic growth. Development and use of a national centralized database containing donor and recipient characteristics and outcomes should be established for quality improvement, self-assessment, and research purposes.

CONCLUSION

TA-NRP is a powerful technique to increase the donor pool for solid organ transplantation. A key advantage includes mitigation of ischemic injury and simultaneous recovery of both abdominal and thoracic organs.[33] Published data demonstrate excellent short-term and mid-term thoracic allograft outcomes. The consensus guidelines published herein serve to standardize practice, monitor outcomes to ensure quality, improve team communication, and preserve public trust in the donation process.

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REFERENCES

1. 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;40:1408–1418.

2. Cain MT, Park SY, Schäfer M, et al. Lung recovery utilizing thoracoabdominal normothermic regional perfusion during donation after circulatory death: the Colorado experience. *JTCVS Tech*. 2023;22:350–358.

3. James L, Reed LaSala V, Hill F, et al. Donation after circulatory death heart transplantation using normothermic regional perfusion: the NYU Protocol. *JTCVS Tech*. 2023;17:111.

4. Urban M, Castleberry AW, Markin NW, et al. Successful lung transplantation with graft recovered after thoracoabdominal normothermic perfusion from donor after circulatory death. *Am J Transplant*. 2022;22:294–298.

5. Zhou AL, Ruck JM, Casillan AJ, et al. Early United States experience with lung donation after circulatory death using thoracoabdominal normothermic regional perfusion. *J Heart Lung Transplant*. 2023;42:693–696.

6. Choi K, Spadaccio C, Ribeiro RVP, et al. Early national trends of lung allograft use during donation after circulatory death heart procurement in the United States. *JTCVS Open*. 2023;16:1020–1028.

7. Gomes BM, Ribeiro RV, Alvarez JS, et al. Normothermic regional perfusion (NRP) during heart DCD recovery: is lung quality impacted? A pre-clinical study. *J Heart Lung Transplant*. 2020;39:S353–S354.

8. Louca J, Öchsner M, Shah A, et al. WISPGm. The international experience of in-situ recovery of the DCD heart: a multicentre retrospective observational study. *EClinicalMed*. 2023;58:101887.

9. Ahmed HF, Kulshrestha K, Kennedy JT, et al. Donation after circulatory death significantly reduces waitlist times while not changing post-heart transplant outcomes: a United Network for Organ Sharing analysis. *J Heart Lung Transplant*. 2023;43:461–470.

10. Urban M, Castleberry AW, Duncan KF, et al. Thoracoabdominal normothermic perfusion in donation after circulatory death. *Ann Thorac Surg*. 2022;113:e473–e476.

11. Fiedler AG, DeVries S, Czekajlo C, et al. Normothermic regional perfusion surgical technique for the procurement of cardiac donors after circulatory death. *JTCVS Tech*. 2022;12:113–115.

12. Trahanas J, Hoffman JR, McMaster WG, et al. DCD organ procurement with normothermic regional perfusion. 2022. https://doi.org/10.25373/ctsnet.19699936.v1

13. 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*. 2022;36:e14659.

14. 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.

15. Thomas J, Chen Q, Roach A, et al. Donation after circulatory death heart procurement strategy impacts utilization and outcomes of concurrently procured abdominal organs. *J Heart Lung Transplant*. 2023;42:993–1001.

16. DeVita MA, Brooks MM, Zawistowski C, et al. Donors after cardiac death: validation of identification criteria (DVIC) study for predictors of rapid death. *Am J Transplantation*. 2008;8:432–441.

17. DCD progression calculator. Accessed October 21, 2023. https://medschool.cuanschutz.edu/surgery/divisions-centers-affiliates/transplant/calculators/dcd-progression

18. Lewis J, Peltier J, Nelson H, et al. Development of the University of Wisconsin donation after cardiac death evaluation tool. *Prog Transplant*. 2003;13:265–273.

19. He X, Xu G, Liang W, et al. Nomogram for predicting time to death after withdrawal of life-sustaining treatment in patients with devastating neurological injury. *Am J Transplantation*. 2015;15:2136–2142.

20. de Groot YJ, Kompanje EJO, Shutter LA, et al. Prediction of potential for organ donation after cardiac death in patients in neurocritical state: a prospective observational study. *Lancet Neurol*. 2012;11:414–419.

21. Nijhoff MF, Pol RA, Volbeda M, et al. External validation of the DCD-N score and a linear prediction model to identify potential candidates for

organ donation after circulatory death: a nationwide multicenter cohort study. *Transplantation*. 2021;105:1311–1316.

22. Kotsopoulos AMM, Vos P, Jansen NE, et al. Prediction model for timing of death in potential donors after circulatory death (DCD III): protocol for a multicenter prospective observational cohort study. *JMIR Res Protoc*. 2020;9:e16733.

23. Croome KP, Barbas AS, Whitson B, et al; American Society of Transplant Surgeons Scientific Studies Committee. American Society of Transplant Surgeons recommendations on best practices in donation after circulatory death organ procurement. *Am J Transplant*. 2023;23:171–179.

24. Dhanani S, Hornby L, van Beinum A, et al; Canadian Critical Care Trials Group. Resumption of cardiac activity after withdrawal of life-sustaining measures. *N Engl J Med*. 2021;384:345–352.

25. Zorko DJ, Shemie J, Hornby L, et al. Autoresuscitation after circulatory arrest: an updated systematic review. *Can J Anaesth*. 2023;70:699–712.

26. Sánchez-Cámara S, Asensio-López MC, Royo-Villanova M, et al. Critical warm ischemia time point for cardiac donation after circulatory death. *Am J Transplant*. 2022;22:1321–1328.

27. American Society of Anesthesiologists (ASA): Committee on Critical Care Medicine, Ethics, and Transplant Anesthesia. Statement on controlled organ donation after circulatory death. Accessed October 21, 2023. https://www.asahq.org/standards-and-practice-parameters/statement-on-controlled-organ-donation-after-circulatory-death

28. 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;42:1161–1165.

29. Ribeiro R, Alvarez J, Yu F, et al. Assessment of cerebral perfusion and activity during normothermic regional perfusion in a porcine model of donation after circulatory death. *J Heart Lung Transplant*. 2021;40:S234.

30. Manara A, Shemie SD, Large S, et al. Maintaining the permanence principle for death during in situ normothermic regional perfusion for donation after circulatory death organ recovery: a United Kingdom and Canadian proposal. *Am J Transplant*. 2020;20:2017–2025.

31. Royo-Villanova M, Miñambres E, Sánchez JM, et al. Maintaining the permanence principle of death during normothermic regional perfusion in controlled donation after the circulatory determination of death: results of a prospective clinical study. *Am J Transplant*. 2023;24:213–221.

32. Rance G, Srey R, Shapeton AD, et al. A quick reference tool for goal-directed perfusion in cardiac surgery. *J Extra Corpor Technol*. 2019;51:172–174.

33. 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*. Published online March 21, 2024. https://doi.org/10.1016/j.ajt.2024.03.027