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CONSENSUS STATEMENT

Donor heart and lung procurement: A consensus statement

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Heart and lung procurements are multiphased processes often accompanied by an array of complex logistics. Approaches to donor evaluation and management, organ procurement, and organ preservation vary among individual procurement teams. Because early graft failure remains a major cause of mortality in contemporary thoracic organ transplant recipients, we sought to establish some standardization in the procurement process. This paper, in this vein, represents an international consensus statement on donor heart and lung procurement and is designed to serve as a guide for physicians, surgeons, and other providers who manage donors to best optimize the clinical status for the procurement of both heart and lungs for transplantation. Donation after brain death (DBD) and donation after circulatory determination death (referred to as donation after circulatory death [DCD] for the remainder of the paper) for both heart and lung transplantation will be discussed in this paper. Although the data available on DCD heart donation are limited, information regarding the surgical technique for procurement is included within this consensus statement. Furthermore, this paper will focus on adult DBD and DCD heart and lung procurement.
Currently, no certification, which is either recognized and/or endorsed by the transplant community at large, exists for the training of a cardiothoracic procurement surgeon. Nevertheless, establishing a training curriculum and credentialing requirements are beyond the scope of this paper.
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Arrival at the procurement site: Evaluation of current donor support

Evaluation of donor heart and lungs is a multistep process that begins many hours or even days before the surgical procurement. Initial assessment includes a review of the donor history, cause of death, laboratory results, and imaging including both computed tomography scan and echocardiography. The procuring surgeon may use a donor checklist to prevent glaring omissions (Figure 1).[1] Any relative contraindications to transplantation should be ruled out, such as transmission of an infectious disease.[2−5] Blood group and chest size are first determined to be compatible, and the tissue types acceptable for transplantation. If the donor has been designated as an increased risk, the recipient or the recipient's proxy is informed, and separate informed consent is duly obtained.

Certain causes of brain death may directly affect the thoracic organs. Table 1 lists the causes of brain death with specific risks that are best addressed at the procurement center. The ultimate goals of donor management are to preserve the donation opportunity and to maximize the number and quality of donor organs for transplantation. Equally important is maintaining an unbiased and collaborative approach without prioritizing 1 organ over another. Timely and frequent communication among the surgeons and other team members is thus essential both within and between the procuring teams.

The brain-dead donor

The goals of management of the donation after brain death (DBD) donor include optimizing cardiac filling pressures, maintaining adequate arterial pressure for donor organ perfusion, ensuring a patent airway and maintaining protective ventilation strategies, and maintaining metabolic homeostasis.[6−8] The recommended approach to the management of the DBD donor is summarized in Figures 2 and 3.[9]

Monitoring

Arterial and central venous lines are required to allow continuous monitoring of the donor hemodynamic status. In

Upon Arrival at the Procurement Center
1) Consent for Donation
2) Verification of Brain Death that complies with local legislation if a DBD donor
3) ABO Compatibility to the recipient
4) Serologies
5) Supplies – tubing for preservation solution, preservation solutions, sternal saw, surgical equipment, bronchoscope, ice, saline, bags for organs, buckets for organs, transport devices of organs
6) Any new information about the donor history since acceptance or any changes in the donor since acceptance to arrival at the procurement center

Loor G; Shumway SJ, McCurry KR et al. Process Improvement in Thoracic Donor Organ Procurement: Implementation of a Donor Assessment Checklist. Annals Thoracic Surgery. 2016; 102(6): 1872-1877.

Figure 1 Donor procurement checklist.

Table 1 Causes of Death Affecting the Thoracic Organ Donor

Cause	Description
Trauma	Cardiac and pulmonary contusions, myocardial stunning, neurogenic pulmonary edema
CVA	Indication of possible hypertension in the donor, left ventricular hypertrophy, coronary artery disease, peripheral arterial disease
Asphyxia	Primary respiratory failure, if unwitnessed unknown downtime
Drug intoxication	Possible drug-induced problems. That is, cocaine, methamphetamines—coronary artery disease—indicates the need for possible left heart catheterization; heroine—high-risk contractible disease potentially
Malignancy	Central nervous system malignancy not necessarily a contraindication to donation

Abbreviation: CVA, cerebral vascular accident.

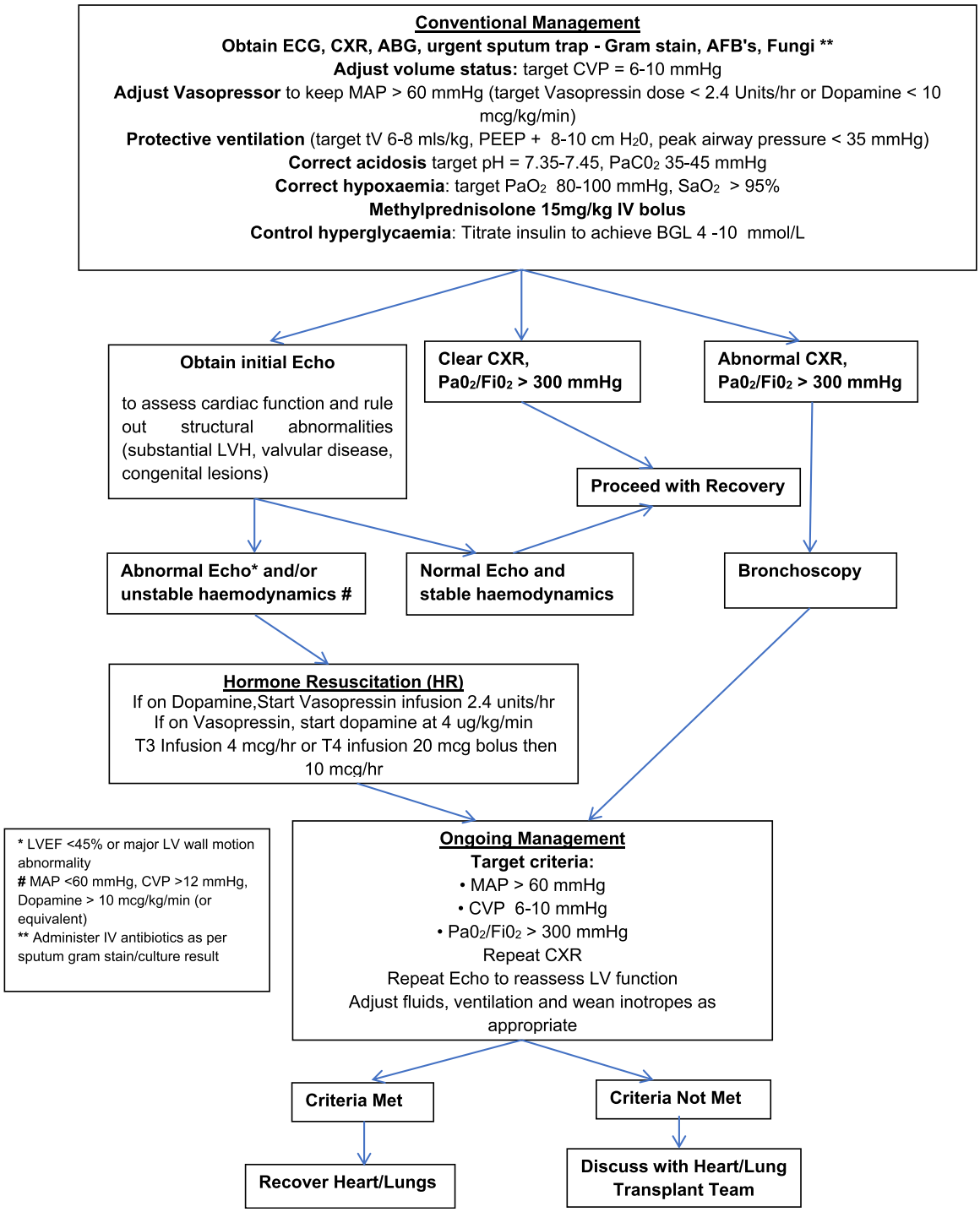

Figure 2 Donor heart and lung management algorithm. ABG; arterial blood gas; CVP, central venous pressure; CXR, chest x ray; ECG, electrocardiogram; LV, left ventricle; LVEF, left ventricular ejection fraction; LVH, left ventricular hypertrophy; MAP, mean arterial pressure; PEEP, positive-end expiratory pressure.

Brain Death Organ Donation
Pathophysiological Management

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Lines, Monitoring and Investigations: (maintain stability)

1. Arterial line and CV line ☐
2. Continue physiological support; document observations Q1H ☐
3. Review medications, cease unnecessary orders ☐
4. Bloods (U&E's, LFT's, FBC, COAG, Blood Grp, ABGs) ☐
5. CXR; ECG ☐

Ventilation (paO2 80 – 100 mmHg, pH 7.35 – 45)

1. Review ventilation, ensure lung protective strategy ☐
   TV 6-8ml/kg ideal body weight, PEEP (8 -10cm H_2O), PIP < 35mmHg, avoid hyperoxemia
2. 30^0 head of bed elevation ☐
3. Circuit humidification ☐
4. Q3H chest physio: Lung recruitment procedures, bronchoscopy if required ☐
5. Continue respiratory adjunct therapy: bronchodilators, antibiotics if indicated ☐

Cardiovascular (MAP 60 – 80 mmHg)

1. Optimise intravascular fluid status ☐
   correct hypovolemia, avoid hypervolemia, Hb >7g/dl, CVP 6 -10
2. If vasogenic hypotension -> vasopressor infusion ☐
   start with **vasopressin (0.6 – 2.4 U/hr)**
3. If inotropes are needed: consider PA and cardiac output monitoring ☐
   add dopamine (4 -10 mcg/kg/min) or norepinephrine (up to 0.2 mcg/kg/min) as inotropes

Fluids and Metabolic Management

1. Review fluid administration. IV crystalloid maintenance fluid ☐
2. Maintain urine output between 0.5-2.5 ml/kg/hr ☐
   If polyuria > 200mls/hr consider Diabetes Insipidus maintain normovolemia, Na<150mM/l with additional free water, treat DI with vasopressin, or DDAVP 1-4 mcg prn
3. Continue NG feeding or TPN ☐
4. Insulin infusion to keep blood sugar at 4 – 10 mM/l ☐
   minimum 1 unit / hr and add a glucose containing fluid if required to maintain blood sugar

General Cares

1. Maintain normothermia with surface warming ☐
2. Anti-embolic stockings, SCDs, low dose heparin or LMWH ☐
3. Eye care, mouth cares, turns and pressure cares ☐

Other Special Instructions

..... ☐
..... ☐
..... ☐
..... ☐

Physiological Goals		Documentation: Achieved: Yes / No OR Not measured: n/a														
Date:	Check in Times:															
PaO_2	80 – 100mmHg or SaO2 92- 100%															
MAP	60 – 80 mmHg															
CVP	6 – 10 mmHg															
Temp	36 -37.5 °C															
BSL	4.0 – 10.0 mM/l															
Urine Output	0.5 - 2ml/kg/hr															
Serum Na	135 – 150 mM/l															

Comments and Notes.....
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1. **Notify Medical Officer immediately if parameter goals are not met.**
2. **Notify DonateLife Donation Specialist promptly if deterioration in parameters.**

DONATION SPECIALIST COORDINATOR	CONTACT NUMBERS	DONATION SPECIALIST COORDINATOR	CONTACT NUMBERS

adapted from the Donor Optimisation Extended Care Bundle developed by United Kingdom NHS for donation after brainstem death

Figure 3 Brain death donor management pathophysiological management.

donors with a low mean arterial pressure (MAP) (i.e., MAP < 60 mm Hg) despite adequate central venous pressure (CVP) (i.e., CVP of 6−10 mm Hg), a pulmonary artery (PA) catheter is also desirable.[8,10] If a PA catheter is not used, direct intraoperative measurement of pressures of the PA and left atrium is recommended.[11] Potential lung donors require continuous oxygen saturation and end-tidal carbon dioxide monitoring (where available) at regular intervals (at least daily or more frequently at the discretion of the donor management team), arterial blood gases and daily chest radiographs, and computed tomography scans of the thorax. A PaO_2:FiO_2 (P/F) ratio >300 mm Hg (40 kPa) generally indicates that the lungs are suitable for transplantation, although a lower value does not necessarily indicate that the organ(s) is unsuitable for donation.[12]

All potential heart donors require a transthoracic echocardiogram or transesophageal echocardiogram (TEE) to evaluate ventricular function and left ventricular wall thickness so

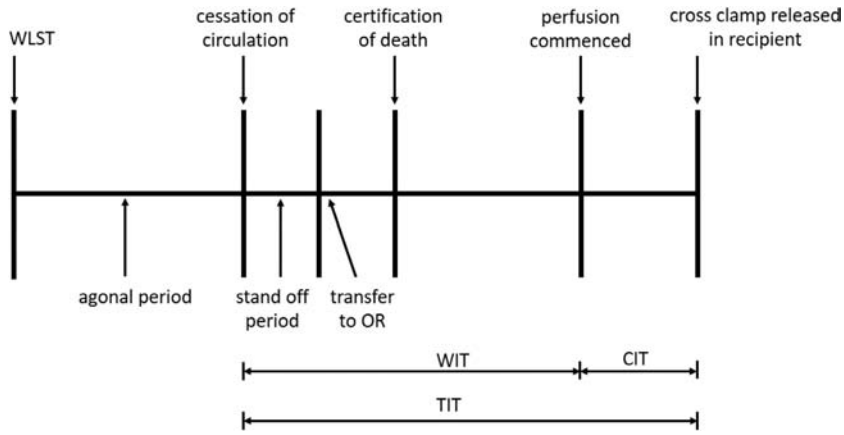

Figure 4 DCD lung procurement procedure. CIT, cold ischemic time; DCD, donation after circulatory death; OR, operating room; TIT, total ischemic time; WIT, warm ischemic time.

as to rule out major valvular or structural heart diseases. Wall motion abnormalities that do not correspond with any particular coronary artery distribution are common after brain death.[13–15] In addition, ventricular dysfunction and hemodynamic optimization, particularly in pediatric donors, may improve with time.[16,17] However, the heart may not necessarily recover, and repeated echocardiograms as frequently as every 12 hours may be indicated. Donor coronary angiography should be performed in potential heart donors with risk factors for coronary artery disease (CAD)—such as those with hypertension; a history of cocaine, heroin, or amphetamine use; significant smoking history or current smoker; age > 40 years; hyperlipidemia; pre-mature CAD; or who have regional wall motion abnormalities on echocardiography.[18,19] All diagnostic studies should be carefully reviewed at the procurement hospital and evaluated in conjunction with donor physiologic status such as inotrope and/or pressor support requirements at the time of procurement.

Fluid management

One of the most important goals in maintaining organ perfusion during donor management is achieving euvolemia. Most organ donors are at risk of intravascular volume depletion to loss of vascular tone and increased capillary permeability. Diabetes insipidus (DI) and hyperglycemia may also compound further losses, increasing the risk for hypovolemic shock.[20] In donors with decreased pre-load, crystalloid solutions (0.9% sodium chloride or Ringer's lactate) are the preferred choices for fluid repletion and maintenance.[21,22] Dextrose containing fluids or hypotonic solutions, such as 0.45% sodium chloride, may be used in patients with hypernatremia (Serum Na^+ > 145 mmol/liter) after correction of hypovolemia. Sodium bicarbonate may be added to treat metabolic acidosis.[23] Careful fluid management avoids massive crystalloid infusion, which has a detrimental effect on arterial oxygenation. Surgeons should evaluate the lungs for pulmonary edema at the donor hospital. Rapid increases in intravascular volume may adversely affect right ventricular function as well as potentiate acute kidney injury.[21–23]

Ventilator and airway management

Protective lung ventilation strategies may prevent additional lung injury. This is achieved by limiting tidal volumes lowering driving pressures and optimizing positive end-expiratory pressure (PEEP)[24–27] (Figure 2). Gentle recruitment maneuvers are ideally performed after tracheal suctioning or temporary disconnection of the ventilator circuit.[28] In addition, limiting PaO_2 to <500 mm Hg potentially limits subsequent bronchiolitis obliterans in lung recipients.[29] Decreasing the FiO_2 once an evaluation is completed may mitigate any inadvertent collateral damage to the lungs. If the patient is PEEP-dependent, tracheal suctioning is performed only in the presence of airway secretions to avoid derecruitment and to evaluate for endobronchial lesions.[30] The endotracheal tube cuff is inflated to a pressure high enough to prevent aspiration.[31] Bronchoscopy is performed early for an accurate evaluation of bronchitis, aspiration, obtaining sputum samples, and possibly bronchoalveolar lavage if an infection is suspected, and to clear stagnant secretions that may cause atelectasis[32] or inhalation injury.

In DBD donors, regional differences in perfusion and gas distribution may occur owing to obstruction by excessive secretions, atelectasis, infection, inflammation, bronchospasm, and gravitational forces resulting in ventilation-perfusion mismatch and/or dead space ventilation, which may result in hypoxemia. Specific treatments include mucolytic therapy, antibiotics as guided by sputum microbiology, and steroids. Higher PEEP in combination with recruitment maneuvers, use of protective strategies, and judicious use of diuretics may be necessary to further reduce ventilation-perfusion mismatching and diffusion abnormalities, thereby increasing the P/F ratio.[33] Intraoperative measurement of the CVP and PA pressure guides diuretic therapy. Bronchoscopy should be repeated at procurement and findings should be compared with previous findings. Bronchoscopic biopsies, sputum

sampling and/or bronchoalveolar lavages, and cultures are important options to assess for infection and malignancy.

Inotropic and vasopressor support

Approximately 90% of brain-dead donors develop progressive hypotension despite adequate fluid resuscitation, necessitating vasopressor support.[20,34] There is no consensus regarding the vasopressor of choice. Observational studies have suggested that the use of catecholamines may result in divergent effects on different organs. One large retrospective analysis reported that administration of catecholamines was associated with improved post-transplant outcomes for renal recipients but with worse outcomes for cardiac recipients.[35] More recently, vasopressin at the lowest dose necessary has emerged as the recommended first-line agent.[12,20] This V1 and V2 receptor agonist increases systemic vascular resistance, although simultaneously preventing DI. Its use has been associated with improved donor heart function (possibly by allowing withdrawal of catecholamine support) and increased recovery of donor organs.[36,37]

Dopamine may be considered an alternative first-line agent, particularly in patients requiring inotropic support.[21,23] A large prospective, randomized, placebo-controlled trial of low-dose dopamine (4 μg/kg/min) demonstrated that dopamine administration to donors already receiving norepinephrine <0.4 μg/kg/min resulted in reduced requirements for post-transplant dialysis in both renal and heart transplant recipients from the same donor.[38] Moreover, overall survival was improved in the heart recipients.[39] Epinephrine and norepinephrine may also be used to achieve desired hemodynamic goals; however, their use may lead to downregulation of β-receptors in the donor's heart, which may affect contractility after transplantation.[40] Higher doses of these agents (>0.2 μg/kg/min) have been reported to increase the risk of cardiac injury,[35,41,42] although in recent literature, the use of norepinephrine in the donor has been deemed safe. Angleitner et al[43] reported no significant differences in 30-day and 1-year mortality, primary graft dysfunction, and the need for renal replacement therapy after heart transplantation when heart donors who did not require vasopressors were compared against those who were on low-dose norepinephrine (0.01−0.1 μg/kg/min), or when those on low-dose norepinephrine (0.01−0.1 μg/kg/min) were compared with those on higher-dose norepinephrine (>0.1 μg/kg/min).[43] Recipients who received hearts from donors on norepinephrine had prolonged intensive care unit (ICU) length of stay.[43] Hence, echocardiograms should be interpreted in the context of vasopressor(s) support that the donor was receiving at the time of the study and may need to be repeated.

Hormone replacement therapy

Brain death results in a rapid decline in serum levels of cortisol, anti-diuretic hormone, thyroid hormones, and insulin.[20] The role of steroid administration in multiorgan donors in combination with thyroid hormone and vasopressin administration has been studied.[44] In animal studies, early administration of methylprednisolone has been associated with significant preservation of both systolic and diastolic cardiac function and a reduction in pro-inflammatory cytokines such as interleukin-6 and tumor necrosis factor-α.[20] In lung transplantation, high-dose corticosteroid administration is associated with improved oxygenation and increased success rate of lung procurement when compared with controls.[45] To achieve these benefits, methylprednisolone is best administered as soon as brain death is confirmed and the patient declared a potential organ donor. Recent studies suggest that low-dose corticosteroid replacement (e.g., 300 mg hydrocortisone) achieves similar improvements in hemodynamic stability and lung oxygenation with less hyperglycemia than high-dose methylprednisolone.[46,47]

The use of vasopressin in the treatment of vasoparesis after brain death is well established.[37] A decrease in anti-diuretic hormone leads to DI and rapid fluid shift which, when combined with decreased sympathetic vascular tone, dramatically increases the risk of hypotension, hypernatremia, and hemoconcentration. Approximately 80% of donors develop DI.[20] Treatment should be considered in patients with 1 or more of the following features: polyuria (urine output > 3 ml/kg/hour or 3 liters/day), increased serum osmolality, decreased urine osmolality, and/or hypernatremia (serum Na^+ > 145 mmol/liter).[48] The use of desmopressin may be considered in normotensive donors and has been associated with increased yield in donor organs.[49,50] Continuous infusion of low-dose vasopressin that is titrated to urine output goal <3 ml/kg/hour decreases urine output although improving MAP. Doses >2.4 U/hour have been associated with adverse cardiac effects and should be avoided.[21]

The role of thyroid hormone replacement therapy in multiorgan donors is still debated. In a number of retrospective studies, hormone replacement with thyroxine has been associated with an increased organ procurement rate for transplantation. However, this has not been demonstrated in prospective randomized trials.[44] We conclude that the use of thyroid hormone replacement may be considered for managing low ejection fraction (<45%) or hemodynamically unstable donors but efficacy remains uncertain. Hyperglycemia is common in donors after brain death secondary to decreased insulin production, insulin resistance, gluconeogenesis, and administration of dextrose containing maintenance fluids and corticosteroids.[20] Most resources suggest maintaining blood glucose levels between 4 and 10 mmol/liter (72−180 mg/dl) or per individual institutional protocols.[12,21,22]

Antibiotics

Clinical signs of infection and, importantly, microbiology results should guide the use of antibiotics, and prophylactic use of antibiotics after brain death is not clinically warranted. A review by an infectious disease specialist is prudent.[51]

Intraoperative management

In DBD donors, spinal reflexes may remain intact, and a muscle relaxant may be required to prevent somatic responses to

Table 2 Acceptable Heart Donor Criteria

Characteristics	Description
Age	Less than 55 years
Echocardiogram	Ejection fraction 55%–65%; posterior left ventricular wall thickness <11 mm; septal wall thickness <11 mm; absence of any valvular disease, damage, and/or vegetations; no wall motion abnormalities
Normal left heart catheterization	For age 40 years or greater or other indication (i.e., cocaine use history)
Donor-recipient weight	This is used for size matching; 20% mismatch in weight is acceptable. Programs often select a range of acceptable size match for donor and recipient. Studies have shown that kg for kg body weight., a female heat has 10% less muscle mass than a male heart. Most programs would require a larger donor and preferably male donor for a redo sternotomy recipient, the presence of pulmonary hypertension or LVAD and/or TAH explant recipient.
Gender	Males tend to be larger. When considering accepting a female donor heart for a male recipient, female size should be 10% larger in height and weight.

Abbreviations: LVAD, left ventricular assist device; TAH, total artificial heart.

surgical stimuli.[52] The duration of donor surgery can vary markedly, particularly when the abdominal procurement team splits the liver in situ before removal. Significant fluid shifts can occur, and blood transfusion may be required in the event of significant bleeding. A lung-protective ventilation strategy that minimizes tidal volume to 6 to 8 ml/kg should be continued. Hemodynamic and metabolic targets should be maintained up to the time of organ removal.

Donor heart and lung assessment and evaluation at the procurement hospital

After reviewing the general donor checklist and the management of the donor before arrival, the procurement team will assess any changes that have occurred between acceptance and arrival at the procurement center, including updated donor history, clinical events and management, imaging, and laboratory results. The acceptable heart and lung donor criteria are summarized in Tables 2[53] and 3,[9] respectively. Failure to meet all donor acceptance criteria does not necessarily preclude organ donation for an appropriate recipient. When offered donor organs, the transplant team should make a decision to accept or decline on the basis of a combination of clinical experience, center experience, and clinical knowledge, including the acuity of the recipient. The decision to proceed with procurement should be made by the procurement team in conjunction with the transplanting team.

Table 3 Acceptable Lung Donor Criteria

Characteristics	Description
Donor PAO_2/FIO_2 ratio	Ratio > 400 (FIO_2 = 1.0, PEEP = 5–8 cm H_2O)
Donor age	Less than 55 years
Smoking history	<20 pack-year
Chest radiograph	Normal chest radiograph without infiltrate
Bronchoscopy	Normal bronchoscopy without significant secretions
Sputum	Absence of organisms on sputum gram stain

Abbreviation: PEEP, positive end-expiratory pressure.

Intraoperative assessment of the donor

Brain death typically results in a form of myocardial injury that is manifested by a depressed ejection fraction.[54] An intraoperative TEE during the procurement should be performed if deterioration of cardiac function is suspected. Trace or mild atrioventricular valve regurgitation will not usually deter procurement. Valvular stenosis is of concern when severity is moderate or severe. If the echocardiogram or coronary angiogram results are not available before arrival at the procurement hospital, the procurement surgeon should personally review the images in search of any unreported anomalies before initiation of surgery.

The procurement surgeon should pay particular attention when assessing for potential CAD. Every effort should be made to prevent donor-transmitted CAD as it may result in a 2- to 3-fold increased risk of primary graft failure and early onset of transplant vasculopathy,[18,55] which are both associated with increased morbidity and mortality after heart transplantation. With a 20% prevalence of significant atherosclerotic lesions (defined as at least 50% stenosis) in the organ donor pool, a careful donor heart evaluation, including coronary angiography, should be performed in patients with risk factors previously discussed.[56] In this situation, clear and timely communication between the procuring and transplant teams, particularly with a sicker recipient, may best inform the decision to appropriately proceed with transplantation. Often during the procurement surgery, the surgeon will palpate the coronary arteries for evidence of calcific disease. This technique has not been established as a method to determine CAD. However, in the absence of coronary angiography, most procurement surgeons would be reluctant to accept a donor heart with palpable calcifications in the coronary arteries.

When procuring donor lungs for transplantation, bronchoscopy may identify anatomic anomalies or signs

suggestive of significant aspiration or pulmonary infection. Copious purulent secretions that cannot be cleared, severe mucosal erythema, and copious bleeding on contact may be grounds for declining the organ. The presence of bronchial anomalies requires communication with the transplanting team as this may influence the decision regarding recipient selection. Of course, there are several other reasons why donor lungs may be declined intraoperatively, for example, identification of a lesion, which is suggestive of malignancy, unrecognized diffuse emphysematous changes, etc.

Cardiac arrhythmias of all varieties may occur in up to 20%–30% of donors.[57,58] These range from supraventricular and ventricular tachycardias to conduction disorders with associated bradycardia. Sinus tachycardia is the most common. The cause of arrhythmias in the donor is multifactorial and may include hypovolemia, hypotension, hypothermia, electrolyte and acid–base disturbances, the concomitant use of sympathomimetics, and myocardial contusion.[23] In the event a donor heart cannot be cardioverted out of atrial fibrillation, the procuring and transplanting surgeons should discuss organ suitability and likely decline the organ for transplantation. To protect the viability of the heart, therapy for arrhythmia should be initiated early, including the correction of any reversible factors,[58] targeting a heart rate between 60 and 120 beats per minute. Tachyarrhythmias that trigger hemodynamic instability should be treated with synchronized electrical cardioversion, and internal defibrillator paddles should be readily available from the time of sternotomy. All members of the team should duly be made aware. Clinically significant bradycardia in brain-dead donors may not respond to atropine owing to a lack of vagal activity. Therefore, a direct-acting chronotropic agent, such as epinephrine (0.2–0.1 μg/kg/min), dopamine (2–5 μg/kg/min), or isoproterenol (2–10 μg/kg/min) or dobutamine (up to 5 μg/kg/min), may instead be used.[57,58] Furthermore, hypothermia, defined as core temperature <36°C, is arrhythmogenic and should be avoided. Schnuelle et al[59] evaluated 3-year survival after heart transplant on the basis of the donor core body temperature on the day of procurement and found that a decreased core body temperature correlated with decreased heart transplant recipient survival.

Visual and tactile assessment of the thoracic donor organs

A median sternotomy is the incision of choice for heart and/or lung procurements. When lungs are involved, some prefer to extend the incision cephalad to the thyroid cartilage as this can allow better exposure of the arch vessels and access to an extended length of the trachea, particularly when the organs will be subjected to ex vivo perfusion. Visual inspection of the heart is performed to evaluate atrial and ventricular sizes. The heart should be inspected visually and by palpation to exclude thrills, chamber enlargement, ventricular hypertrophy, coronary calcification, areas of transmural scarring, and abnormalities of contractility. Though difficult to see, palpable myocardial scarring, where it exists, may signal coronary disease. Distention of the right atrium, right ventricle, and contractility of the right ventricle should be assessed. Careful manual palpation of the heart is typically performed to assess for potential coronary calcifications, though there is no evidence to validate this technique. The presence of a small amount of milky fluid commonly observed in the pericardium of a brain-dead patient is of little consequence. Presence of mediastinal hematomas from chest compressions and/or thoracic trauma obliges the surgeon to consider the possibility of myocardial contusion. The pericardium may also be adherent to the heart from previous intrathoracic events. Soft adhesions may be divided sharply with minimal contact with the epicardium. If adhesions are dense and close, the heart should likely be declined for donation.

Visual inspection of the lungs should include an appraisal of color, inflation, scarring, signs of infection, atelectasis, contusion, nodules, tumors, bullae, blebs, and adhesions. Intrathoracic adhesions should be lysed carefully so as not to injure the visceral pleura. Because of the need for immunosuppression after transplantation, a parenchymal injury may result in a chronic air leak in the recipient. Lungs with significant visceral pleural injury may not be suitable owing to the possible risk of deflation during storage and the possibility of significant air leak following implantation. Small apical blebs can be left alone or excluded by stapling. If there is any concern about obstructive physiology or impaired compliance, further evaluation is warranted. Flow-volume loops may be captured but require an ICU ventilator. Peak and plateau inspiratory pressures should be recorded at set tidal volumes to determine compliance. Following recruitment and maximal inflation, the lungs should be temporarily disconnected from the ventilator to assess elastic recoil, evidenced by swift and complete deflation. If nodules are present and concerning, a frozen section biopsy may be performed before the procurement to determine the suitability of the lung(s).

When atelectasis is encountered, a gentle sustained Valsalva is preferred to vigorous hand bagging with high-peak pressures. Once the lungs have been recruited, it is important to restore the ventilator to standard lung-protective evaluation settings (tidal volume = 6–8 ml/kg, FiO_2 = 1.0, and PEEP of 5 cm hydrogen dioxide). A minimum interval of 25–30 minutes should be allowed before assessing successive blood gases to avoid falsely high or low values. If atelectasis does not respond to recruitment or rapidly recurs after recruitment, the lung may not be suitable for transplantation. These findings should prompt repeat bronchoscopy to search for reversible (mucus plugs) or irreversible (aspirated material, infection) causes.

The use of individual pulmonary venous gas measurements (performed after lung recruitment with FiO_2 of 1.0 and PEEP of 5–8 cm hydrogen dioxide) may predict organ dysfunction after transplant in the recipient and should be performed if there is concern regarding the function of a lobe or segment of the lung or if the PF ratio is <300.[60,61] Pulmonary venous gases should be strongly considered as a routine if a single lung transplant is planned.

Surgical technique

Preliminary dissection

The aim of the preliminary dissection is to isolate all the key structures to enable prompt explant after donor organ preservation.[62] The steps are as follows: (1) pericardial stay sutures with tags to allow lung evaluation; (2) circumferential dissection of the superior vena cava (SVC) to separate it from the right PA; (3) circumferential dissection of the inferior vena cava (IVC); (4) depending on surgeon preference, the azygous vein may be encircled and divided between ligatures at this stage; (5) the aorta and PA are separated sufficiently to allow for cross-clamp application and may be encircled with an umbilical tape depending on surgeon preference; (6) the pleurae are widely opened anteriorly; (7) the pulmonary ligaments may be divided if accessible; and (8) the trachea lying posteriorly between the proximal aorta arch and SVC is dissected free and may be encircled with an umbilical tape after the heart is explanted. Some surgeons prefer to dissect the trachea at a later time in the procurement. Division of the innominate vein and artery can facilitate access if the vessels are not needed for the heart transplantation. At this point, if the abdominal organs are being procured, both teams should communicate their readiness to proceed.

Communication

Conflicts between organ procurement teams may arise and usually revolve around certain key issues. The first is the timing of the dissection and excision of organs. If the donor is hemodynamically stable, it is reasonable to wait until all the organ procurement teams have completed their preliminary dissection. If the donor is unstable, teams should move expeditiously, so that organs are not compromised. Agreement regarding the anatomic boundaries between organs is another common source of discord. Disagreement may arise between the heart and lung procurement teams as to where to divide the left atrium, where to divide the main PA, and where and how to vent the heart. The liver and heart teams may disagree on the level of IVC transection.

The following are some strategies to avoid conflict at procurement:

- At least 1 person from all the parties should be fluent in the same language.
- The procuring heart, lung, and abdominal surgeons should ideally have significant experience with the implantation of their own organs. This helps surgeons to estimate the anatomic margins they need to safely complete the implant.
- The procuring team should ideally have experience with the other teams' implant procedure. Indeed, where surgeons perform both heart and lung procurements, there are generally fewer disagreements.
- Venting and explant strategies should be agreed on before aortic cross-clamp.
- Agree on all cut lines before they are made.
- Once the cross-clamp is placed, the donor may be infused with more than 10 liters of preservation solution. It is necessary to ensure that an adequate number of suction units is made available to accommodate the volume. It is best to inform the procuring operating room (OR) staff that there is potential for a flush solution to spill over onto the floor, to be careful, and to be prepared with towels.
- Clear visualization. If the pericardial well is relatively dry, it is much easier to identify the anatomic boundaries of the cut zones during explant.
- Open the interatrial groove. Peeling the wall of the left atrium off the right atrium effectively lengthens the left atrium, increasing available anatomy to be used by both the heart and lung teams.

Timing

Communication of the key time points and events in the peri-operative procurement process should be relayed clearly among the procurement teams and to the transplant teams. Transplant centers should develop a standard protocol of communication between these teams. The following is a suggested protocol that may be modified to accommodate local preferences:

1 The time at which the procurement teams are required to be at the donor hospital should be communicated to all parties. Considering the travel time required, each procurement team can then set their respective times of departure.
2 The transplant surgeon should select a time for the recipient to arrive at the OR, and this time should be communicated with the attending anesthesiologist and the OR staff.
3 A member of the procurement team should contact the transplant center

a On arrival at the donor hospital.
b When the donor arrives in the OR.
c At the completion of the heart and/or lung evaluation.
d With an estimated time of donor heparin administration to which the other procuring teams are already in agreement.
e When ready to administer heparin. Receive confirmation from the transplanting surgeon(s) that timing is still appropriate.
f When ready to place the aortic cross-clamp. Receive confirmation from the transplanting surgeon(s) that timing is still appropriate.
g On departure from the donor hospital with an estimated time of the organ arriving at the transplant center.
h Fifteen minutes (or another duration requested by the transplant surgeon) before the organ reaches the transplant center.

The above outline is a general outline of the most important times and/or events in the procurement process. Transplant centers and surgeons can accommodate the timing of

the phone calls and the frequency of the phone calls to the center and/or surgeon preference.

Preparations and cannulation

A 4-0 polypropylene purse-string suture is placed in the mid-ascending aorta and another 4-0 polypropylene purse-string is placed on the main PA 1.5 cm proximal to its bifurcation. These will be the sites of cannulation for purposes of infusing the preservative solutions. The PA is cannulated at a point agreed upon by the heart and lung recovery teams. This avoids inadvertently placing it too close to the pulmonic valve sinuses. It is important to stay distal to the sinuses of the PA to avoid distortion when the suture is subsequently tied. The timing of heparin administration is agreed on by all members of the team, and all teams will have checked with their respective implanting surgeons. The donor is systemically anti-coagulated with a rapid push of 400 U/kg of intravenous heparin.

Aortic cross-clamp and cardiac and pulmonary preservation

After the cannulae are secured, the lines are de-aired and connected. Prostaglandin E (250 μg) can be injected through the pulmonary arterial cannula or directly into the PA. The SVC is either tied or clamped, and the IVC is partially transected anteriorly. Venting of the abdominal venous drainage may be achieved above and/or below the diaphragm. Once opened, a pool-tip sucker should be placed into the IVC, which will effectively drain the abdominal perfusate. This is crucial to prevent warm venous blood and abdominal perfusate from flooding into the heart and lungs, thereby causing right heart distension. When both the heart and liver teams are procuring organs, IVC transection is best accomplished when neither the heart nor liver is under traction. If the lungs are to be procured, the warm blood from the divided IVC must be prevented from reaching the pleural space. Venting of the left atrium ensures that the left ventricle is decompressed, so that the cardiac preservation solution reaches the entire myocardium. Failure to decompress will compromise the preservation of the cardiac graft. If lungs are not being procured, the simplest strategy is to divide the right superior pulmonary vein at the pericardial reflection and place a sump tip sucker into the left atrium. If both the lungs and heart are being procured, it is important to use a venting strategy that is optimal for both teams. A total of 3 strategies commonly used include the following:

- Opening or excision of the left atrial appendage. This is simple and can be performed with minimal manipulation of the heart.
- A large incision in the left atrial wall anterior and medial to the left pulmonary veins. In this venting strategy, the apex of the heart is reflected anteriorly, medially, and superiorly, thereby exposing the coronary sinus and the left atrium leading to the left pulmonary veins. However, this mandates an early decision between the lung and heart teams about where to divide the left atrium.
- An incision in Waterston's interatrial groove and vent using active suction passed into the LV.

Table 4 Reasons to Decline Lungs at the Procurement Center

Inability to recruit
Unacceptable PaO_2:FiO_2 (P/F) ratio
Unanticipated confirmation of primary or non-primary malignancy
Severe trauma not appreciated on CT
New data on non-compatibility
Demise of original recipient during transit
Withdrawal of consent from the donor's decision maker

Abbreviation: CT, computed tomography.

In summary, the essential suction devices include 1 in the IVC, 1 in each pleural cavity, 1 in the left atrium, and 1 in the abdomen. This is the ideal situation; however, the authors understand that the number of suction devices is dependent on the availability and capacity of the procuring hospital to provide the available and necessary number.

Furthermore, 3–5 cardiac cycles are followed to allow the heart to empty. At this point, gentle traction on the previously placed umbilical tape allows an aortic cross-clamp to be applied across the proximal aortic arch, and cardiac preservation fluid is infused into the aortic root. The surgeon should ensure that there is sufficient aortic root pressure and that the heart arrests promptly and remains decompressed. After the cardiac preservation solution has begun, the lung preservation solution is initiated, which typically contains an additional 250 μg of Prostaglandin E in each 2.8-liter bag. The pericardial stays are retracted medially to allow flushing of the chest with cold saline or cold preservation solution and access to the pleural spaces. All efforts are made to avoid pooling of warm blood in the pleural cavities. Some also avoid direct contact of ice on the lungs as it can cause tissue injury (Table 4).

Heart explantation[62,63]

Dissection sequence

When the infusion of cardiac preservation solution is complete, the following steps are taken:

- IVC transection is completed.
- The left atrium is incised in Waterston's groove, leaving an adequate left atrial cuff connecting the right superior and inferior pulmonary veins.
- From the groove, the left atriotomy is extended cephalad for 1−2 cm and caudad for 1−2 cm.
- The heart is then lifted and displaced to the right to expose and incise the left atrium midway between the coronary

sinus and the confluence of the left-sided pulmonary veins. The left atriotomy is extended caudad for 1−2 cm.
- The heart is then lifted directly cephalad, and the left atrial incisions from the right and left side are connected inferiorly.
- Applying anterior traction on the heart, the right and left atriotomies are connected superiorly.
- The right sub-clavian and jugular veins are transected to release the SVC and provide maximum length.
- The aortic cross-clamp is removed, and the aorta is transected as distally as possible.
- Then, the heart is returned to its anatomic position and gentle caudad traction is applied. This exposes the main PA, which is transected at its bifurcation.

For certain circumstances, such as a recipient with complex congenital heart disease who may require reconstruction of the pulmonary arteries, additional tissue may need to be procured either in continuity with the donor heart or separately, such as the descending thoracic aorta or innominate vein. Specific technical issues from donor organ procurement that may impact results include procuring inadequate left atrial cuff, obtaining adequate SVC length to avoid sinoatrial nodal injury, and procuring sufficient aortic length for recipients undergoing left ventricular assist device explant or for congenital heart disease recipients.

Heart inspection, management, and packaging

The heart is then removed and taken to the back table for inspection and packaging. The following steps are taken:

- The heart is examined for any anatomic anomalies such as a patent foramen ovale and atrial or ventricular septal defects. The presence of a normal coronary sinus orifice should be confirmed to exclude the very rare abnormality of coronary venous drainage to an extracardiac vein. The valves are inspected to ensure the leaflets are intact and to check for adhesions. The heart is inspected to make sure there is no evidence of endocarditis or an intracardiac mass. The heart is also examined for hematoma that may be due to cardiopulmonary resuscitation of the donor.
- The heart is placed in a basin of cold (4˚C) solution (saline or cardiac preservation solution may be used).
- All chambers are irrigated copiously with a cold solution.
- Delivery of additional antegrade coronary perfusion with cardioplegia solution is optional.
- Place the heart in a sterile bag containing 1,000 ml of solution at 4˚C. Seal the bag. Place this bag in a second bag containing 1,000 ml of cold solution, and seal that bag (3 bags may be used). This protects against contact-mediated hypothermic injury, an often underappreciated cause of graft failure.[64]
- Then place in a rigid sterile container filled with a cold solution. Seal tightly, and then place in a crushed ice-filled cooler. The protocol of the United Kingdom is to place the heart in 2 liters of cold saline in each of the 3 bags to prevent contact with ice and minimize the risk of freezing the organ. (Note: ideal heart temperature is probably around 5˚C−10˚C. Direct contact of ice with the myocardium may cause freezing. Freezing of any part of the heart is undesirable because freezing and thawing cause irreversible cellular damage). There are some new technologies for packaging to prevent freezing.[65]
- The packaged heart is placed in a container and labeled with the appropriate regulatory and other necessary information.

Lung explantation[61]

After the donor heart has been removed and packed, a further 1 liter of lung preservation fluid is given in a retrograde fashion and divided equally between the 4 pulmonary veins. Retrograde perfusion should be continued until the effluent from the PA is clear. The donor lungs are then ready for explant.

Dissection sequence

To remove the lung block, incise the posterior aspect of the pericardium from lateral to medial on both sides, exposing the esophagus centrally. Detaching the diaphragm from the anterior chest wall facilitates greater opening of the rib spreader. It is critical to stay cephalad to the IVC and avoid injury to the inferior aspect of the lower lobes or the hepatic veins.

- The right lung is reflected out of the right chest, and the pulmonary ligament is incised.
- The mediastinal pleura lateral to the esophagus is incised vertically.
- The azygos vein is transected.
- This plane of dissection is extended cephalad to obtain circumferential control of the trachea.
- The right lung is then returned into the chest, and the left lung is reflected out of the chest.
- The left inferior pulmonary ligament is incised, followed by the mediastinal pleura along the esophagus.
- The attachments to the anterior wall of the esophagus are incised, and the distal aortic arch is transected as the surgeon approaches it. A finger is placed in the proximal end to apply upward and rightward traction. This will allow the dissection to follow the esophageal wall and a continued opening of the tissues over the lateral wall.
- Finishing the release of these connections from the back of the block to the anterior wall of the esophagus.
- The left lung is returned to the chest.
- Of note, dividing the atria and pulmonary arteries at this point before reinflation and before removal to the back table may be preferable to some and so is optional. However, many surgeons prefer to do this at the back table, transporting the lung en bloc. If this option is elected, divide the right and left PAs at the bifurcation. If the pulmonary arteries are divided, then the atrial cuffs are divided vertically in the midline.
- The lungs are reinflated to make sure there is no posterior or inferior atelectasis. Inflation of the lungs before explantation may also offer some protection from ischemic damage.

- Inflation is held at a static pressure of 12–15 cm of water pressure, and a double staple line is applied to the trachea distal to the tip of the endotracheal tube and proximal to the carina. The lungs should not be over- or underinflated. Two 3.5-mm loads of the thoracoabdominal stapler are used.
- The lungs are then placed on the back table. One hand is placed behind the block to palpate the posterior wall of the trachea and mainstream bronchi.
- Soft tissues and pericardium anterior to the proximal left main stem are divided. Some surgeons elect to divide the lungs at the time of procurement. The following steps detail the process of the division of the lungs at the procurement hospital.
- A double staple line is then applied to the proximal left main stem with 2 of the 3.5-mm staple loads of the thoracoabdominal stapler, and the bronchus is divided between them. Care must be taken not to apply this stapler to the crotch of the carina because this may inadvertently injure the right main stem. In addition, one must be careful not to denude the tissue while stapling.
- Some surgeons flush an additional liter of retrograde pneumoplegia delivered into the pulmonary veins for each lung until the effluent is clear as it returns retrograde from the PA. If one performs back table retrograde flush, this can be performed in the storage back container and the effluent can serve as the storage solution.

Lung inspection and packaging

Inspect the lungs for surgical damage, areas of inadequate flush, or persistent atelectasis. Often, the posterior aspects of the organs are difficult to visualize in situ, and a more thorough assessment is now possible. Communicate any abnormal findings or concerns to the transplanting team immediately. Place each lung in a separate sterile bag labeled with corresponding laterality containing 1,000 ml of lung preservation solution at 4˚C. Seal the bag. Place this bag in a second bag containing about 250–500 ml of saline slush and seal that bag. This is placed into a third bag containing an adequate amount of saline slush, and seal this third bag. Another option is the United Kingdom protocol in which one places the lungs in 2 liters of cold saline in each of 3 bags. This is then placed into a rigid sterile container filled with saline slush. Seal tightly, then place in a crushed ice-filled cooler, and label with the appropriate anatomic lung. The packaged lungs are placed in a container and labeled with the appropriate regulatory and other necessary information. Some centers prefer to return with the lung en bloc for a double lung transplant. This practice is center-dependent.

DCD heart donation and procurement

In the DCD setting, the patient is medically managed until the withdrawal of life-supporting therapy. Non-invasive investigations, such as blood sampling, chest radiograph, and transthoracic echocardiogram, may be performed. However, the procuring teams should not be involved in advising on the management of the dying patient, and it is generally considered inappropriate to initiate additional interventions to assess or improve the organs until after death has been certified. Therefore, at the time of donor organ offer, the initial decision to accept a DCD heart is often based on limited donor information (Table 5). Of note, determination after circulatory determination of death

Table 5 Donation after Circulatory Death Criteria

Inclusion criteria	Exclusion criteria
Category III OCD donor	Previous cardiac surgery
Participating OCD donor hospital	Previous midline sternotomy
Age ≥18 to ≤57 years old	Known coronary heart disease
Consent for donation from next of kin	Known congenital heart disease
Expected death within 4 hours of WLST	Previous myocardial infarct
WLST in anesthesia room or ICU	Insulin-dependent diabetes
No valvular abnormalities on echocardiogram	Epinephrine infusion
Ejection fraction > 50% before WLST	Dobutamine infusion
	Norepinephrine > 0.3 μg/kg/min
	Active malignancy
	Hepatitis B antigen-positive
	Hepatitis C antibody-positive
	Malignant melanoma
	All secondary intracerebral tumors
	Human immunodeficiency virus
	Primary intracerebral lymphoma
	Creutzfeldt-Jacob disease
	Tuberculosis

Abbreviations: ICU, intensive care unit; OCD, donation after circulatory-determined death; WLST, withdrawal of life-support therapy.

criteria varies among hospitals and countries. Physicians and surgeons should review the local criteria before acceptance of the donor offer and procurement.

Table 5 shows the selection criteria of DCD hearts.[66]

Techniques for DCD heart procurement

DCD hearts would have been subjected to hypoxia and hypotension before mechanical asystole. This is followed by a mandatory period of warm ischemia before the procurement process can begin. In a canine DCD heart model, pre-reperfusion cardioplegia followed by continuous warm blood perfusion was found to be superior to cold storage.[67] A total of 2 strategies for immediate warm blood reperfusion of the asystolic DCD heart have been described:

- Direct procurement and machine perfusion (DP-MP).[68]
- Thoracoabdominal normothermic regional perfusion (TANRP)[69–71]

The asystolic DCD donor is transferred to the OR with the procurement teams already prepared to begin. If the lungs are also being retrieved, the donor is reintubated to protect the trachea from soiling. A rapid sternotomy and laparotomy are simultaneously performed. The pericardium is opened with an inverted T incision, and boluses of heparin are injected into the right atrium (30,000 IU) and the pulmonary trunk (20,000 IU) simultaneously (1 syringe by the surgeon and 1 by the assistant).

DP-MP

DP-MP involves rapid excision and ex-situ warm blood reperfusion of the asystolic DCD heart. After heparinization, autologous blood from the DCD donor (1.2−1.5 liter) is collected from the right atrium to prime the perfusion circuit, a process that takes up to 90 sec. It is imperative that this donor blood is not cross-contaminated with any organ preservation solution; therefore, all procurement teams are reminded to wait until donor blood collection is completed before commencing perfusion of their organs of interest.

Once blood collection is completed, an aortic cross-clamp is applied to the proximal aortic arch and 1 liter of St Thomas' cold crystalloid cardioplegia (Martindale Pharmaceuticals Romford Essex, United Kingdom) supplemented with erythropoietin and glyceryl trinitrate is delivered into the aortic root. Venting and explant of the DCD heart are similar to those of a DBD heart. The DCD heart is then instrumented on the bench for ex-situ continuous warm blood machine perfusion. During machine perfusion of the donor heart, aortic pressure, coronary flow rate, and perfusate lactate concentrations are all assessed in making a final decision of acceptability of the DCD heart. Once the donor heart has arrived at the transplant center, it is rearrested with cold crystalloid cardioplegia before it is removed from the perfusion device and transplanted into the recipient.

TANRP

TANRP involves a rapid in situ reperfusion of the DCD heart and all the abdominal organs without reestablishing the cerebral circulation. A standard cardiopulmonary bypass circuit can be used for TANRP. Alternatively, a portable extracorporeal membrane oxygenation circuit may be used, but the addition of a hard-shell reservoir facilitates the conduct of perfusion.

After injection of heparin into the asystolic DCD heart as above, the aortic arch is rapidly dissected out to identify and clamp the 3 arch branches with a view to division. The distal ascending aorta is cannulated with a 24-Fr-arterial cannula, and a 2-stage venous cannula is inserted into the right atrium. TANRP is commenced at 5 liters/min. The lungs are reinflated and ventilation is reestablished. The abdominal team should ensure that all the abdominal organs are adequately perfused. The pleurae are opened to check for lung inflation. The airway is examined with fiberoptic bronchoscopy, and lung recruitment is performed if indicated.

Owing to the mandatory asystole period and circulatory arrest, profound acidosis and arterial hypotension are routinely noted upon reestablishing the circulation. Both common iliac arteries are ligated to direct blood flow to the donor organs and help restore perfusion pressure. Spontaneous cardiac activity usually returns within 1 or 2 minutes of TANRP. If the heart fibrillates, a 10 J internal direct current shock may be applied. As soon as the heart is contracting, it is gently loaded with volume by raising CVP to 3–5 mm Hg to allow cardiac ejection and lung reperfusion.

Persistent hypotension (MAP < 50 mm Hg) may be treated with an infusion of dopamine at up to 2.5 μg/kg/min; an infusion of vasopressin (1−4 U/hour) may be added if required. Packed red blood cells, bicarbonate solution, and a hemofilter may be added to the circuit to help achieve the following physiologic targets during TANRP:

1. Systemic temperature	35°C
2. MAP	50 mm Hg
3. Hemoglobin concentration	100 g/liter
4. Base excess	± 2 mEq

When the above targets have been met, which usually takes between 45 and 90 min, the DCD donor is weaned off TANRP, allowing the heart to take over the perfusion of all the donor organs and the lungs to provide a full gas exchange. At this point, functional heart and lung assessments may be performed. Cardiac function is assessed with TEE and right heart catheter. After TANRP, the acceptance

Table 6 DCD Modified Maastricht Classification

Category I Uncontrolled	Found dead IA, out of hospital IB, in hospital	Sudden unexpected CA without any attempt of resuscitation
Category II Uncontrolled	Witnessed cardiac arrest IIA, out of hospital IIB, in hospital	Sudden unexpected irreversible CA with unsuccessful resuscitation
Category III Controlled	Withdrawal of life-sustaining therapy	The planned withdrawal of life-sustaining therapy
Category IV Uncontrolled/controlled	Cardiac arrest while brain dead	Sudden CA after brain death but before plans for organ recovery

Abbreviations: CA, circulatory arrest; DCD, donation after circulatory death.

criteria for a DCD hearts are identical to those for accepting a DBD heart and include the following:

1. CVP	< 12 mm Hg
2. Pulmonary capillary wedge pressure	< 12 mm Hg
3. Cardiac index	> 2.5 liter/min/m^2
4. Left ventricular ejection fraction	> 50%

Blood gas analyses are performed on blood samples from the arterial line and the individual pulmonary veins. A PaO_2 of >35 kPa (260 mm Hg) on FiO_2 of 1.0 and PEEP of 8 cm hydrogen dioxide indicate acceptable donor lung function following TANRP.

If in situ functional assessments are satisfactory after weaning from TANRP, the donor heart and lungs are procured in an identical fashion to a DBD heart and lung procurement. The retrieved DCD heart can be directly transplanted into the recipient if colocated with the donor. For distant procurement, the retrieved DCD heart may be placed on continuous machine perfusion to avoid ischemia during transportation, although successful heart transplantation has recently been described using cold storage during transport for distant procurement.

In addition, successful transplantation after pediatric DCD heart donation has also been described.[72]

Donation after circulatory death for lung procurement

For many lung transplant programs throughout the world, the use of DCD donor lungs substantially increases lung transplant activity, decreasing duration on the waiting list and waitlist mortality. The proportion of recipients receiving DCD donor lungs reported by some centers is substantial (Australia, 28%; Netherlands, 40%; London, 25%; Canada 32%).[69,73,74]

It is important to note that there are biologic, ethical, legal, and procedural differences between DCD and DBD lung donors. The standard criterion for determination of circulatory death is the permanent absence of respiration and circulation. Because circulatory death occurs in differing circumstances, the severity of the ischemic injury to the donor lungs may vary; the Maastricht classification was developed to reflect these differences (Table 6). A modification has been proposed that allows for a Category V for euthanasia in countries, such as Belgium and the Netherlands, where medically assisted circulatory death is legal.[75,76]

The distinction between controlled DCD (where a circulatory arrest is the result of a planned withdrawal of cardiac and ventilatory support) and uncontrolled DCD (where circulatory arrest is unplanned and unexpected) is important as the latter circumstance implies a greater likelihood of lung injury. For the purposes of this document, only Maastricht Category III donors (controlled), which most DCD donors are, will be considered. The results of lung transplantation using DCD donors are no different from those of lung transplantation using DBD donors.[77,78]

The process of procuring lungs from a DCD donor is very different from that of a DBD donor and is outlined in Figure 1. Some of the details of the process will vary depending on the jurisdiction, but the general principles are as follows:

- Advance warning must be given to the OR to prepare for a DCD procurement.
- A pre-withdrawal meeting is convened and the attendees should include attending physicians from the following services: transplant surgery, anesthesia, and critical care medicine (responsible for the withdrawal of care and declaration of death), and OR nursing staff and the ICU bedside nurse, and the organ procurement specialist(s).
- The purpose of the pre-withdrawal meeting is to review the patient's history, particularly any issues that would impact organ quality, review the informed consent, and ensure that all are aware of their roles and responsibilities, especially those for whom this is a first experience. The personnel responsible for communication between the ICU and the OR are identified.
- Principally, on the basis of the wishes of family, a decision regarding the withdrawal time is made. In most programs, withdrawal occurs in the ICU but may occur in the OR an adjacent anesthetic side room. The nasogastric tube is aspirated, inotropic drugs are turned off, and the patient is extubated in the 30° head-up position. Failure to meet the criteria to become an organ donor occurs in approximately 40% of cases.[79,80] A number of

algorithms have been developed to attempt to predict likelihood of progression[81,82] but lack usefulness because of their inaccuracy. From the International Society for Heart and Lung Transplant DCD registry, the median time from withdrawal of life support therapy (WLST) to arrest is 15 min and from WLST to cold perfusion (warm ischemic time) is 30 min. Heparin is administered in those jurisdictions where pre-mortem interventions are permissible. In the International Society for Heart and Lung Transplant DCD registry,[83] only 54% of donors received pre-mortem heparin, but this had no effect on post-transplant outcome. The allowable duration of the agonal phase (the time after WLST[s] in DCD, a time variable period including progressive hypoxia and hypotension, until circulatory arrest occurs and death is defined) or warm ischemic time is unknown, but current evidence suggests that it is up to at least 60 minutes.[84] Because of the apparent tolerance of lungs to warm ischemia, many programs extend the time for WLST to death out to 90 minutes, and in some programs, 120 to 180 minutes. Death is declared when there is a lack of pulsatility on the arterial line with or without electrical activity. This varies by centers, ranging from loss of pulse in unmonitored patients on one extreme to electrocardiogram silence at others.

- Depending on the jurisdiction, there is a stand-off period between 2 and 5 minutes before death can be declared. Thereafter, the donor is expeditiously transported to the OR.
- On arrival in the OR, time out is followed by oral intubation of the donor by the anesthesiologist. A single breath is given to ensure that there is end-tidal carbon dioxide. Thereafter, no further ventilation should occur until the perfusion solutions are commenced or the aorta clamped to avoid the possibility of auto-resuscitation and cerebral reperfusion. The anesthesiologist, physician, or surgeon can also perform a bronchoscopy while the chest is being opened.
- Invariably, thoracic and abdominal organ procurements have to occur simultaneously. The donor is prepped, a rapid median sternotomy is performed, and the pericardium is opened. A hemostat is attached to the adventitia of the PA for retraction and a purse-string suture is placed in the main PA. An infusion line is handed off to the anesthesiologist, the main PA cannulated and connected to the infusion line, and the infusion of the lung preservation solution is initiated (e.g., perfadex at a dose of 50−70 ml/kg). If heparin was not administered pre-mortem, it is added to the perfusion solution (10,000 units of heparin). A large hole is made in the left atrial appendage for egress of the perfusion solution, and the lungs are gently ventilated. Both pleural spaces are widely opened and ice-cold saline or ice slush is used for topical cooling.
- When the perfusion solution has been administered, the lungs are inspected and suitability for transplantation is determined as for DBD lungs.
- The priority is once again given to explantation of the heart, and the remainder of the procedure, including excision of the lungs, separation of the lungs, retrograde flushing of the lungs, and packaging for transport, is identical to that used for DBD lungs.

Conclusion

This paper provides a consensus of the process for donor heart and lung procurement for both adult DBD and DCD donors. The paper provides a framework to review the optimal management of the thoracic organ donor and how variations in practice may impact the quality of the donor organs. It provides a stepwise guide for the assessment of the thoracic donor at the donor hospital, specifically the intraoperative assessment. In addition, this paper provides a summary of the technical aspects of the procurement surgery for maximal benefit to the heart and/or lung transplant recipient(s). Finally, this serves as a template for communication among all team members to prevent delays or other events that may potentially result in the organ(s) being declined for transplantation.

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Supplementary materials

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