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Review Article

Anaesthesia considerations in heart transplantation: A comprehensive review

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ABSTRACT

In over 56 years since the first heart transplant, the science of heart transplantation has evolved from an experimental procedure to an established standard of care for end-stage heart failure. The process involves appropriate patient selection, the listing of recipients, pre-operative optimization, intraoperative management, post-operative care, and follow-up. A robust transplant team, strong government backing, and positive support from the population are essential criteria for the success of any transplant program. Management of heart transplant recipients from the Anaesthesia perspective is challenging due to a myriad of patient risk factors; and the urgent nature of surgery due to the unpredictable nature of donor heart availability. The intraoperative aim is safe induction of anaesthesia, strict asepsis, immunosuppressive therapy, anticipation of major vascular injury, managing pulmonary vascular resistance, ventricular support, optimal ventilatory strategy, and good haemostasis. The postoperative goal is preventing infection, haemodynamic management, gradual weaning of supports, adequate analgesia, monitoring for complications, physiotherapy, and early discharge of the patient from the intensive care unit. There is an increased complexity of heart transplant recipients, due to the increasing use of pre-transplantation mechanical circulatory support devices. The cardiac anaesthesiologist needs to have knowledge of the modern changes in the field of Heart Transplant. The goal of this paper is to provide an overview of the heart transplant origins in India, donor pre-operative workup, intra-operative anaesthesia care, and early post-operative management of heart transplant patients.

1. Introduction

Definition of heart failure- Heart failure (HF) is a clinical syndrome with symptoms and/or signs caused by a structural and/or functional cardiac abnormality, which is confirmed by either elevated natriuretic peptide levels or objective evidence of pulmonary or systemic congestion. As per the Left Ventricular Ejection Fraction (LVEF), HF can be classified as given in Figure 1.[1,2]

1.1. The global burden of heart failure

HF is considered a global pandemic, with approximately 64.3 million people suffering in 2017.[3]

1.2. Heart transplant data

Heart transplantation provides the best outcome for acute or end-stage heart failure. Approximately 8988 heart transplants occurred in the year 2022 worldwide, as per data from 'The Global Observatory on Donation and Transplantation' (GODT).

According to the 'NHS Organ and Tissue Donation and Transplantation Activity Report 2022-2023' (data from 1st

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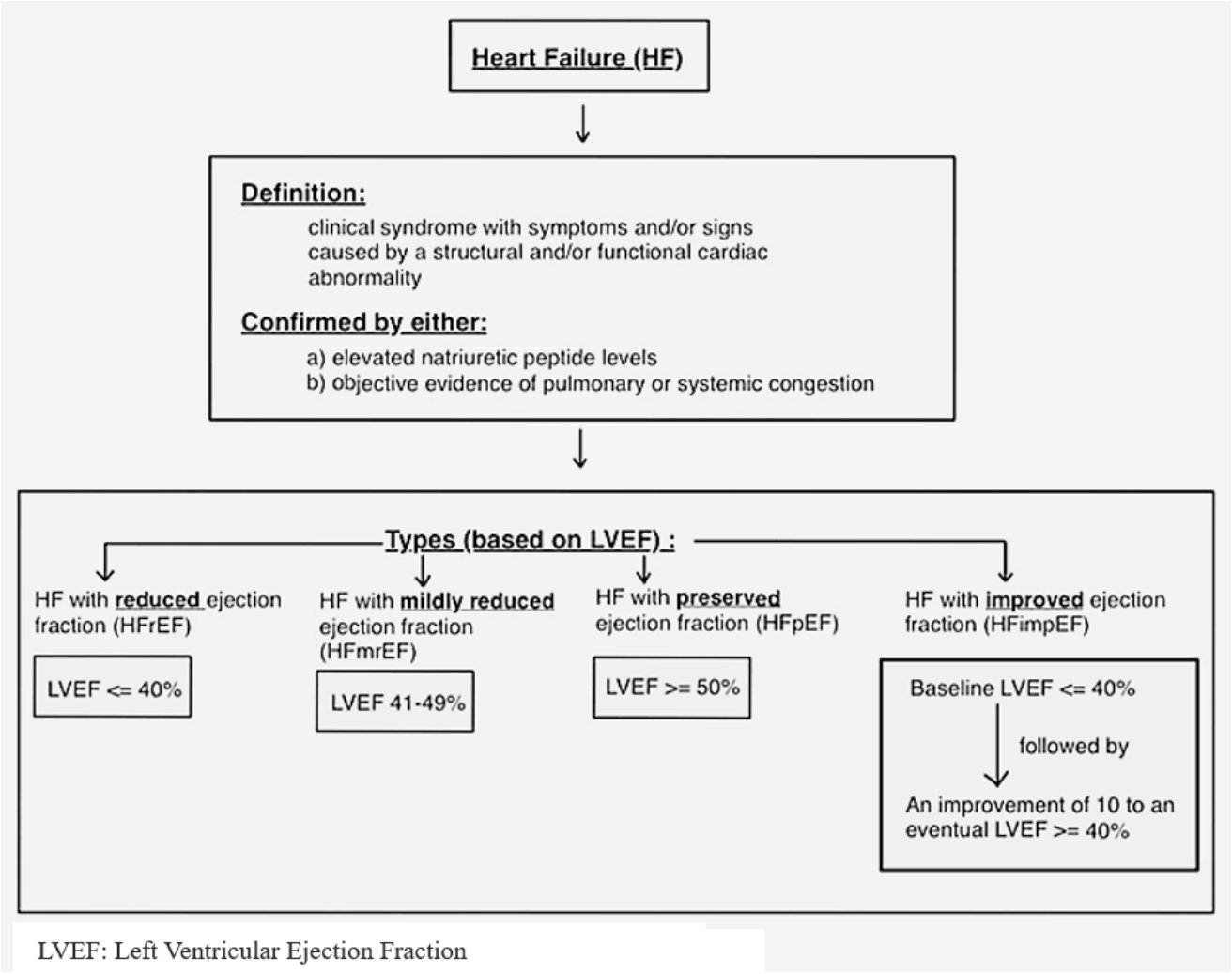

Figure 1: Heart failure definition and types

April 2022 to 31st March 2023) there were 325 new heart transplant registrations in the UK. Out of the 695 patients on the heart transplant waitlist- 384 were still on the waitlist or were suspended temporarily, 212 patients received heart transplants, 81 patients were removed from the waitlist, and 18 patients died while on the waitlist.[4]

The data from 'The Organ Procurement and Transplantation Network (USA)' states that, there are 3434 heart transplant waitlist candidates in the USA as of 20th May 2024. There have been 1445 heart transplants in USA in the year 2024 till 20th May 2024. While there was a total of 4545 heart transplants in 2023.[5] In the year 2020, 76% of candidates were on the waiting list for less than 1 year. Whereas, the proportion of candidates awaiting a transplant between one to two years, rose from 7.6% to 11.7%.[6]

1.3. Indications for transplant

The most common indication for heart transplants has been end-stage non-ischaemic cardiomyopathy followed by ischaemic cardiomyopathy. The other indications being valvular heart disease, congenital heart disease, hypertrophic cardiomyopathy, restrictive cardiomyopathy.[7,8]

1.4. Wait time for transplant

As per 'OPTN/SRTR 2022 Annual data report: Heart', about 45.8% patients had waited time of <90days in USA. With waitlist time ranging from 0 days to >2 years.[9]

1.5. Survival and morbidity post-transplant

As per 'The International Thoracic Organ Transplant Registry of the International Society for Heart and Lung Transplantation: Thirty-sixth adult heart transplantation

report- 2019' the median survival after adult heart transplants performed between years 2002 and 2009 is 12.5 years. Median survival of 14.8 years is seen in recipients surviving the first-year post-transplant. 60% of the surviving recipients were not re-hospitalization in the 1^{st} year, and approximately 75% did not require re-hospitalization in the 2-5 years post-transplant.[10]

As per 'The registry of the International Society for Heart and Lung Transplantation: thirty-first official adult heart transplant report-2014', 1-year survival was 81% and 5-year survival was 69%, for transplants between 1982- June 2012.[11]

The common long-term causes of mortality after transplantation are graft failure, non-cytomegalovirus infection and multiple organ failure. Other causes of death being malignancy, acute rejection, cardiac allograft vasculopathy, and renal failure.[10]

Due to increasing donor heart requirements, a few countries such as Australia, America, Spain, UK have started accepting hearts from Donation after Circulatory Death (DCD).[12] Prognosis of heart transplant recipients from a DCD donor are similar to from Donation after brain Death (DBD), however there is higher need for postoperative mechanical circulatory support.[13]

In an effort to promote organ donations, there is an increase in the number of countries with an opt-out method of organ donation protocol (e.g. Argentina, Chile, Columbia, Singapore, UK, Spain, France, etc). Here, every citizen is considered a willing prospective organ donor (in the event of death) unless the person or family specifically opts-out from donation.

2. The Indian Experience

On 16 February 1968, Dr. P.K. Sen and his team performed the first human heart transplant in India at 'Seth G. S. Medical College & King Edward Memorial Hospital, Mumbai (erstwhile Bombay)'. It was the fifth cardiac transplant worldwide, and he was the fourth surgeon in the world to perform this historical procedure.[14,15] This was immediately followed by the 6th worldwide transplant by the team.[16]

The Transplantation of Human Organs Act, was passed in 1994, which allowed donation from Brain dead donors (DBD).[17] This was followed by first successful heart transplant in India from a brain-dead donor was performed by Dr. P. Venugopal on 3^{rd} August 1994 at the 'All India Institute of Medical Sciences, New-Delhi'.[18]

Dr. K.M. Cherian performed heart transplant on 22^{nd}-23^{rd} September 1995, in Chennai, the first heart transplant surgery to be performed in a private hospital in India.[19] The first heart-lung transplantation in India was done at Madras Medical Mission, Chennai on 3^{rd} May 1999 by Dr. K.M. Cherian's team.[20–22]

Dr. Jose Chacko Periappuram performed the first heart Re-transplant in Kochi, on 6^{th} March 2014.[23]

Figure 2 shows Indian data for the total number of heart transplants from the year 2013 to 2022[24]

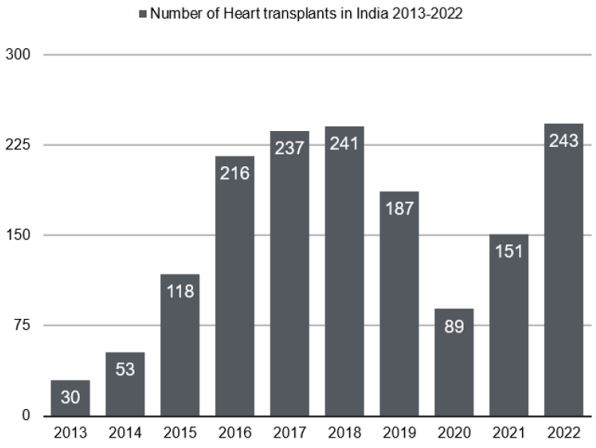

Figure 2: Data for organ donation and transplantation (2013-2022) (National organ & tissue transplantation organisation, DGHS, Ministry of Health & Family Welfare, Govt. of India)

Table 1 shows the Indian number of organ donation, organ utilization and heart transplants that occurred in the year 2022.

Table 1: Deceased organ donation evolution for India (Year 2022)

		Number	Per Million Population
Total Organ Donors	Actual	941	0.7 pmp
	Utilized	920	0.7 pmp
Heart Transplant	Total	243	0.2 pmp

Indian Population: 1428.5 million (population data from https: //www/unfpa.org/data/world-population-dashboard)

PMP: Per million population

3. Anaesthesia Perspective

Management of heart transplant recipients from the Anaesthesia perspective is challenging due to a myriad of patient risk factors; and the urgent nature of surgery due to the unpredictable nature of donor heart availability.

The intraoperative aim is safe induction of anaesthesia, strict asepsis, immunosuppressive therapy, the anticipation of major vascular injury, managing pulmonary vascular resistance, ventricular support, optimal ventilatory strategy, and good haemostasis.

The postoperative goal is preventing infection, haemodynamic management, gradual weaning of supports, adequate analgesia, monitoring for complications, physiotherapy, and early discharge of the patient from the intensive care unit.

There is an increased complexity of heart transplant recipients due to the increasing use of pre-transplantation mechanical circulatory support devices, the number of patients with congenital heart diseases, redo-surgeries, multi-organ transplants, etc.[25] The cardiac anaesthesiologist needs to know about the modern changes in the field of Heart Transplant.

In this review, we describe the peri-operative anaesthesia considerations in adult heart transplant recipients.

Indications and Contra-indications for heart transplantation.[2,26,27]

Table 2: Indication and contra-indication for heart transplantation

Indication	Contraindication
End-stage Heart Failure despite maximum treatment	Active infection
NYHA class III (advanced) or IV	Chronic liver failure (Child-Pugh C)
Episode of heart failure requiring diuretics, inotropes, Recurrent life-threatening ventricular arrhythmias requiring more than 1 hospital admission in a year	Chronic Kidney Disease with eGFR < 30 ml/min/m2
Refractory angina	Refractory PAH: PASP> 60 mmHg, PVR> 5 Wood Units
VO2 max < 12 ml/kg/min	Severe cerebrovascular or peripheral vascular disease
	Severe lung disease
	Active malignancy
	Uncontrolled Diabetes with end-organ damage
	Active drug or alcohol abuse
	Lack of social support, severe psychiatric illness, non-compliant with medical therapy
	Morbid obesity (BMI>35kg/m^2)
	Multi-system disease requiring other organ transplantation

NYHA: New York Heart Association; ICD: Implantable cardioverter defibrillator; VO2: oxygen consumption; eGFR: Estimated glomerular filtration rate; PAH: Pulmonary arterial hypertension; PASP: Pulmonary artery systolic pressure; PVR: Pulmonary vascular resistance; BMI: Body mass index

4. Allocation Criteria

In India, the hospital is expected to perform required investigations of potential heart, lung, and heart-lung transplantation recipients. Who are then registered on the 'NOTTO portal-www.notto.gov.in' by the hospital. Registered recipients are classified as per the Priority listing for organ allocation. Priority allocation criteria for heart, heart-lung: National Organ & Tissue Transplantation Organisation (NOTTO), Govt of India is described in Table 3.[28]

Table 3: Priority allocation criteria for heart and heart-lung recipients (NOTTO, Govt of India)

1. (emergency)	Critical patients requiring mechanical circulatory support (e.g. IABP, VAD) while awaiting transplantation. Their priority is based on blood group and heart size matching. Their status is updated every week.
2. (semi-emergency)	Patients in ICU requiring inotropes or a minimum of 1 week and not tolerating de-escalation of inotropes. Their status is updated every 48 hours. In case of deceased donor organ availability, their status is confirmed by 3 members of the heart subcommittee (appointed by chairman of the subcommittee).
3. (elective)	Recipients on elective transplant list. Their status is updated every month.

IABP: Inta-aortic balloon pump; VAD: Ventricular assist device; ICU: intensive care unit

Organ procurement & transplant network (OPTN) heart allocation criteria, USA is described in Table 4.[29]

5. Preoperative Evaluation & Workup

History[30,31]

1. A detailed history of the present illness is taken, including its duration, and severity. The need for hospitalization, medication for heart failure or arrhythmia, current need for inotropes, presence of pacemaker/Implantable cardioverter defibrillator (ICD), and mechanical circulatory support devices. Aetiology of functional Heart Failure, Heart failure severity grading, and Presence of mechanical abnormality of the heart (e.g. ischaemic, valvular, cardiomyopathy, congenital heart disease) need to be elucidated.
2. History of Pulmonary pathology- presence of COPD, Asthma, Pulmonary arterial hypertension, Pneumonia, Obstructive sleep apnea.
3. Central Nervous System History- Carotid stenosis, Syncope, Stroke, Transient Ischaemic attack.
4. Assessment for Metabolic syndromes- Diabetes, Hypo-hyperthyroidism, autoimmune diseases, etc.
5. Assessment of Renal function- h/o renal failure, renal replacement therapy.
6. Assessment of Hepatic function- the presence of congestive hepatomegaly, cirrhosis, primary liver or gall bladder pathology.
7. Any other significant medical history e.g. recent infections, treated Tuberculosis, treated Malignancy.
8. Previous Surgeries for congenital heart disease (palliative/corrective), valvular surgery, Coronary

Table 4: Adult heart allocation criteria (OPTN, USA)

Status	
1	Veno-Arterial ECMO. Non-dischargeable, surgically implanted, non-endovascular biventricular support device. MCS with life-threatening ventricular arrhythmia.
2	Non-dischargeable, surgically implanted, non-endovascular Left VAD. Intra-aortic balloon pump. VFib/ VTach (without mechanical support). MCS with device malfunction or failure. TAH, Biventricular VAD, Right VAD, or VAD in patients with single ventricle. Percutaneous endovascular MCS.
3	Dischargeable LVAD for discretionary 30 days. Multiple inotropes or single high-dose inotrope (on hemodynamic monitoring). Veno-Arterial ECMO >7 days; percutaneous endovascular circulatory support device or IABP >14 days. Non-dischargeable, surgically implanted, non-endovascular Left VAD >14 days. MCS having device infection, haemolysis, pump thrombosis, right heart failure, mucosal bleed, or aortic insufficiency.
4	Dischargeable Left VAD without discretionary 30 days. Inotropes (not required monitoring). Retransplant. Congenital heart disease (CHD), ischemic heart disease with intractable angina, hypertrophic cardiomyopathy, restrictive cardiomyopathy, amyloidosis.
5	Waitlisting for at least one other organ from same hospital.
6	All other active candidates.

ECMO: Extra-corporeal membrane oxygenation; MCS: Mechanical Circulatory Support; VAD: Ventricular assist device; Vfib: Ventricular fibrillation; VTach: Ventricular tachycardia; TAH: Total artificial heart

artery bypass grafting, previous lung surgeries, Peripheral vascular surgeries and any other surgery.

9. Medication history- Current cardiac medications e.g. diuretics, digoxin, ace inhibitors, beta-blockers, inotropes, antiplatelets, anticoagulants, and antiarrhythmics. Pulmonary medications for asthma, pulmonary vasodilators. Anti-diabetic medication, Insulin, Thyroid medications. Antibiotics/Anti-viral drugs.
10. Anaesthesia history- h/o tolerance to general anaesthesia, and regional anaesthetics.
11. Note H/o drug allergy, transfusion (Allo-sensitization to blood products).
12. Ask about past or current H/o smoking, alcohol, drug abuse, and psychological or cognitive disabilities.

Measurements of- Weight, Height, BMI assessment, Frailty assessment, Blood pressure, heart rate and rhythm.

Investigations: Investigations for pre-transplant workup are mentioned in Table 5 .[32–34]

General consultations obtained from- Psychiatry, Social work, and other clinical services as needed (e.g. Nephrology, Pulmonology, Department of Infectious Diseases, Gastroenterology, etc.)

6. Anaesthesia Assessment[30,31,35–37]

Patient assessment is done as part of a multidisciplinary workup after the patient is listed. The next screening assessment is just before transplant. Screening of history, current status, assessment of systemic functions and recent investigations is done.

Last oral intake is confirmed. General airway assessment is done.

Patient status whether ambulatory, bedridden, or haemodynamically unstable in the intensive care unit is noted.

The severity of Left and Right ventricular dysfunction, pulmonary hypertension, intercurrent deterioration, recent angina, volume status, inotrope requirement, and severity of end-organ damage is assessed.

Recent Haemoglobin, coagulation parameters, platelets, liver and renal function, Blood glucose, infection screen with antibiotic sensitivity reports are assessed along with Transthoracic ECHO, angiography, pulmonary function tests, Cardiac Computed tomography, cardiac catheterization data.

Congenital heart disease (CHD)- patients may be differentiated into those with uncorrected lesions, those who have undergone corrective or palliative surgery and those with a failing single ventricle physiology. May have limited sites for central venous access due to recurrent invasive procedures and abnormal anatomy. Assessment of CT chest is useful to plan venous cannulation, to note safe sternotomy routes, the presence of arterio-venous and veno-venous collaterals. Catheterization data can give further information about pulmonary vascular resistance, and aberrant pulmonary blood flow sources. Patients are screened for the presence of vascular thrombosis and infection foci.

Recurrent procedures or admission- Patients with recurrent central venous procedures have a predisposition to venous thrombosis. Venous Doppler sizing of femoral vessels is noted to prepare accessory sites of emergency peripheral cannulation.

Redosternotomy- History of Previous cardiac surgery is noted. The cardiac chambers might be stuck to sternum and there may be presence of extensive adhesions. The patient may be on anticoagulation (e.g. Fontan surgery or Valve replacement surgery) it predisposes to increased risk of bleeding, vascular injury during sternotomy. There are increased chances of vascular or major cardia chamber injury, bleeding, prolonged cardiopulmonary bypass time. External defibrillator pads, adequate blood products in operating room, rapid blood infusors, and preparation for emergency peripheral bypass should be arranged. Warfarin reversal might be considered.

Table 5: Pre-transplant workup investigations

Immunology	ABO grouping. Panel Reactive Antibody & flow cytometry, Human Leucocyte Antigen tissue typing (to be done at transplant)
Assessment of heart failure severity	CPET (with RER). Electrocardiogram. Trans thoracic Echo. Right heart catheterization (vasodilator challenge if elevated PVR). Coronary Angiography (if indicated) CT Chest (if indicated)
Evaluation of Multiorgan function	Routine tests (Haemoglobin, Platelet count, differential blood count, Liver profile, Sr glucose, Sr Calcium, Sr Potassium, Blood urea nitrogen, SR Creatinine). Coagulation assessment (PT/INR, aPTT). Urinalysis, 24-hour urine for creatinine clearance, Urine protein. Chest X-Ray (PA and Lateral), Pulmonary Function Tests, Arterial Blood Gas. Thyroid Function test, lipid profile. Abdominal ultrasound. Carotid doppler (if indicated or age >50yr). Ankle Brachial Index (if indicated or age >50yr). DEXA scan (if indicated or age >50yr). Dental examination. Ophthalmologic examination (if diabetic). Pregnancy Test (in female patients of childbearing age)
Malignancy assessment	Stool for occult blood. Upper GI endoscopy, Colonoscopy (if indicated or age >50yr). Mammography (if indicated or age >40yr). Gynaecological/Pap smear (indicated >18yr age, or sexually active). PSA, digital rectal examination (men >50yr).
Infectious Serology	HBs Ag, HBs Ab, HBc Ab. Hep C Ab, HIV. Rapid Plasma Reagin/VDRL. Herpes Simplex Virus IgG, Cytomegalovirus IgG, Toxoplasmosis IgG, Ebstein Barr Virus IgG, Varicella IgG. Tuberculin Test. Hep B surface Ab titre (for assessment of immunity).

CPET: Cardio pulmonary exercise testing; RER: Respiratory exchange ratio; PASP: Pulmonary artery systolic pressure; CT: Computed tomography; PT/INR: Prothrombin time/ International normalized ratio; aPTT: Activated plasma thromboplastin time; PSA: Prostate-specific antigen; HBs Ag: Hepatitis B surface Antigen; HBs Ab; Hepatitis B surface Antibody; HBc Ab Hepatitis B core Antibody; Hep C Ab: Hepatitis C Antibody; HIV: Human Immunodeficiency Virus; IgG: Immunoglobulin G

Table 6: Describes the pre-transplant optimisation protocol for recipients[34]

Pre-transplant optimization	
Cachexia (Frailty assessment)	Cardiac Rehabilitation. Nutritional support to augment calorie intake. appetite stimulants. Total Parenteral Nutrition. micronutrient supplementation and bone mineral density improvement.
Pre-Transplant Body mass index	Candidates with Body mass index <18.5kg/m^2or >35kg/m^2tend to have decreased survival
Diabetes	Diet control Oral Hypoglycaemic Agents Insulin
Psychosocial issues	Support groups for substance abuse, counselling, medical therapy for psychiatric illness.
Haemodynamic optimization for Pulmonary Arterial Hypertension	Medical management of Left Ventricular Failure. Diuretics, inotropes, iv Nitroglycerine, nitroprusside. Inhaled pulmonary vasodilators (e.g. nitric oxide, prostacyclin). PDE-3 inhibitors (milrinone). PDE 5 inhibitors (sildenafil). Endothelin receptor antagonist (bosentan, macitentan).
Haemodynamic optimization for Left Ventricular failure	Mechanical circulatory support
Vaccination	Live virus vaccine- complete 4 weeks prior to transplant (e.g. Measles Mumps Rubella, varicella, live attenuated zoster, and rotavirus) Inactivated vaccines- complete 2 weeks prior to transplant (Tetanus, Pertussis, Influenza, Pneumococcal Hepatitis A, Hepatitis B, and Human Papilloma Virus vaccine) Booster : Influenza vaccine (yearly), Pneumococcal Vaccine (5yearly). (Recombinant subunit zoster vaccine is preferred compared to live attenuated vaccine.)

PDE: Phosphodiesterase

Implantable Electronic devices- Cardiac Resynchronization Therapy (CRT), Implantable cardioverter defibrillator (ICD), and pacemaker is noted. Long duration of the device may predispose to lead fibrosis causing vessel narrowing. The leads may also be a nidus for infection. Respective company personnel are informed about the expected timing of surgery for device inactivation intraoperatively.

Mechanical circulatory devices- consists of IABP, ECMO, Ventricular Assist Devices (VAD). Patients may be on heparin, or warfarin. Vitamin K, Fresh Frozen plasma, and prothrombin complex concentrate may be required peri-operatively.[37] Dissection around Ventricular assist devices might be difficult due to anticipated injury to the cardiac chambers.

Medication- patients on ACE inhibitors, Angiotensin Receptor blockers, Beta-blockers, Nitrates, Hydralazine may have perioperative hypotension or vasoplegia. Patients on warfarin, antiplatelet agents will be predisposed to increased bleeding; hence preparation for warfarin reversal, and increased blood product transfusion must be considered.

Consent- Informed written consent is to be taken for transplant, anaesthesia, risk of anticipated complications during surgery, invasive lines, blood transfusion, elective or emergency ECMO institution, unanticipated increase in ICU stay, immunosuppression-related complications, organ failure, renal replacement therapy, risk of morbidity and mortality.

7. Timing and Preparation of Surgery[37]

In our Institute, the Pre-operative protocol is as follows:

1. Consent form and paperwork is confirmed. Fasting status is noted and patient is kept nil-by-mouth.
2. Leukocyte depleted, irradiated, CMV negative cross-matched 6 units each of packed RBC, FFP, and Platelet are arranged. Part preparation is done, along with nasal application of mupirocin ointment as MRSA prophylaxis.
3. Intravenous access is secured. Inj. Vitamin K 10 mg i.m. stat, Inj. Ceftazidime 1g i.v. stat, Inj. Teicoplanin 400mg i.v. stat, Tab. Thyroxine 25 mcg p.o. stat, and Tab. Mycophenolate mofetil 500mg p.o. stat is administered pre-operatively. Sedative agents are preferably avoided in an uncontrolled ward environment.

The goal of co-ordination at induction is to reduce graft ischaemia time, and pre-implantation time for the recipient to minimal. The donor heart should be inspected by the retrieval team, and the anticipated duration of donor heart travel time be calculated prior to anaesthetic induction of the recipient.

Approximately, 1 hour should be considered for induction of anaesthesia and 1 hour for surgical dissection. 2 hr of pre-implantation surgical dissection time should be considered for recipients undergoing redo-sternotomy.

Recipient heart explantation is undertaken only after the donor's heart is inspected at the recipient's operating room by the head surgeon.

8. Anaesthesia Management[31,35–38]

A good co-ordination of the operating theatre team is of essence. The operating theatre team including Cardiac Anaesthesiologist, Senior Transplant Surgeons, Nurses, Technicians, Perfusionists should be available at induction. Company Technician must be available for CRT, Pacemaker, ICD interrogation, inactivation or reprogramming. In a patient with VAD, a practitioner trained in device management be present in the operating theatre till the device is removed.

Strict aseptic techniques are followed as the patient will be immunosuppressed post-operatively. Equipment and drugs are prepared as per routine on-pump cardiac surgeries. External defibrillator pads are to be applied. Standard monitoring (includes Pulse oximetry, 12 lead ECG, End-tidal CO2 monitor, Temperature monitor) and Cerebral oximetry using Near Infra-red Spectroscopy. Two Large-bore venous cannula and an arterial line is secured prior to anaesthesia induction. Ultrasound-guided Arterial line insertion can be done in the presence of Left VAD (due to non-pulsatile blood flow).

Central Venous Cannulation with Pulmonary Artery catheter placement after induction of anaesthesia (line should be secured before induction in very-high-risk patients). The right internal jugular vein may be reserved for future endo-myocardial biopsy access.

Preoperative inotropes, vasopressors, vasodilators, and pulmonary vasodilators infusions to be ready (e.g. Inj. Adrenaline, Nor-Adrenaline, Dobutamine, Nitrates, Milrinone, Levosimendan).[2] Inotropes can be started just prior to induction to offset the sudden hemodynamic instability due to loss of intrinsic sympathetic tone, peripheral vasodilation, and negative inotropic effect of induction agents.

Induction: The aim at induction is to achieve rapid airway control with minimal myocardial depression and pulmonary vascular resistance, maintain systemic vascular resistance and preload.

The patient is considered to have a full stomach due to inadequate fasting and delayed gastric emptying. The modified rapid sequence induction is preferred for quickly securing the airway.

Patients may have exaggerated hypotensive responses to standard doses of sedative and opioid analgesics, and peak haemodynamic and hypnotic effects of drugs are delayed due to low cardiac output. Induction of anaesthesia must be gradual and titrated to effect, with adequate time for systemic drug circulation.

In our centre we use Inj. Midazolam 0.5mg i.v., Inj. Fentanyl 5mcg/kg i.v., Inj. Etomidate 0.25mg/kg i.v., Inj. Rocuronium 1-1.2mg/kg i.v. at Induction.

Ventilation- Tidal volume of 6-8ml/kg, adequate Positive end-expiratory pressure, a higher fraction of inspired oxygen (FiO2) used. Hypoxia, hypercarbia, atelectasis, and acidosis increase Pulmonary vascular resistance (PVR) which predisposes to RV failure. Nitrous oxide increases PVR, hence avoided intraoperatively.

9. Maintenance Anaesthesia

Other lines and monitors are placed after Anaesthesia Induction such as: -

1. Pulmonary Artery catheter (for cardiac output, mixed venous saturation, and PA pressure monitoring),
2. Orogastric tube (for gastric decompression),
3. Transoesophageal ECHO (for assessing bi-ventricular function, volume status, intra-cardiac thrombus, vegetations, valvular abnormality, shunts, effusion, aortic atheroma, adequacy of de-airing, readiness for weaning bypass etc.),
4. Foley's catheter (for urine output measurement).
5. Balanced anaesthesia is maintained with air, oxygen mixture. Isoflurane, sevoflurane or propofol is used to maintain depth of anaesthesia. Inj. Fentanyl (for analgesia) and Inj. Rocuronium (for muscle relaxation) infusion is continued. Infusion of Inj. Atracurium as a muscle relaxant is used in patients with deranged liver and kidney function..
6. Hypotension is managed with fluid preloading and vasopressors for maintaining systemic vascular resistance, inotropes are added to increase cardiac contractility. Progressive haemodynamic instability may require urgent initiation of CPB. In patients with LVAD, a reduction in preload to the device may result in a low flow alarm. This is managed by intravenous fluid administration, followed by reduction in LVAD pump speed..
7. Antibiotics and immunosuppressants are administered after anaesthesia induction as per institutional protocol. Inj. methylprednisolone (1 gram i.v. is generally given after induction and 500mg i.v. at aortic cross-clamp release)..
8. Patients with a history of cardiac surgery have a higher risk of vascular injury at sternotomy. Femoral vessels are prepared before sternotomy for emergency initiation of peripheral Cardiopulmonary Bypass due to anticipated injury, bleeding and air embolism. Blood products are kept ready in the operating room. Cell saver and Rapid blood infusion system are on standby. An antifibrinolytic (Inj. Tranexamic Acid) is given to reduce bleeding and transfusion requirements.

10. Surgical Considerations

Sternotomy is followed by dissection of the aorta, pulmonary artery, Superior and Inferior Vena Cava. Pleural effusions are to be drained to reduce airway pressure. LVAD is to be mobilized. The Pulmonary Artery Catheter is withdrawn before Bi-Caval cannulation.

Before aortic cannulation, Inj. Heparin 400 U/kg i.v. is administered, to target activated clotting time > 480 sec.[39] Heparin resistance can be managed by repeat heparin dose, Fresh frozen plasma administration, or antithrombin III concentrate (500 U i.v.) in patients with antithrombin III deficiency.[40]

High Aortic cannulation is done. Venous cannulae are placed in Superior and Inferior Vena Cava.

In Redo-surgeries, the femoral artery and femoral/axillary vein are cannulated for initiation of peripheral Veno-Arterial Bypass to decompress the heart, followed by central cannulation after cardiac dissection.

When the patient has been supported on an LVAD, at the time of transplant the patient is transitioned to CPB via standard Aorto-bicaval cannulation, CPB is commenced and outflow graft of the LVAD is clamped and the VAD is turned off. The Aorta is cross-clamped and the VAD hardware is removed from the surgical field.[37,41]

The recipient's heart is explanted by transecting the Cavae, Aorta is transected proximal to the clamp, the pulmonary artery is transected prior to its bifurcation and the LA is transected keeping a broad cuff around the pulmonary vein which will be later matched to the donor LA cuff. Donor-recipient Aorta and Pulmonary Artery are anastomosed, Aortic cross-clamp is released. Then Donor-recipient SVC and IVC anastomosis is completed on a beating heart.[42] Atrial and Ventricular pacing wires are fixed to the myocardium.

11. Preparation for Separating from CPB[30,31,36,37]

Inj. Methylprednisolone 500mg is administered just before cross-clamp release. Steep Trendelenburg position, and temporary mechanical carotid artery compression is achieved to prevent systemic air and debri embolism at cross-clamp release.[43] The Temporary pacemaker and transoesophageal echocardiography (TOE) machine is confirmed in operating room. Inotropes, vasopressors, and pulmonary vasodilators are kept available.

After cross clamp release, at least 1 hour reperfusion time is given to support the heart, especially for prolonged graft ischaemic time. While gradually rewarming (to >35.5degree centigrade) the patient on complete CPB, heart is allowed to eject while partly filled. ABG, Sr. electrolytes, Haemoglobin, Glucose levels are assessed. Lines are zeroed. De-airing of heart is confirmed using TOE.

Arrhythmias at cross-clamp release and weaning from CPB are managed by continued CPB support, increasing

perfusion pressure, and maintaining Sr Potassium levels. Ventricular fibrillation or Ventricular tachycardia is managed by Internal defibrillation (10-30 Joules), Inj. Magnesium, Inj. Amiodarone and Inj. Lignocaine. Sinus bradycardia is managed by Inj. Isoproterenol i.v., Inj. Adrenaline i.v. or Atrial pacing.

11.1. Inotropic support

As the transplanted heart is denervated, there is a loss of direct sympathetic and parasympathetic input. The response to circulating catecholamines are blunted. Indirect-acting drugs (e.g. Atropine, glycopyrrolate, ephedrine) will not elicit a response. Cardiac output of denervated heart is dependent on chronotropy and preloading.

Following are the recommendations of medications as per 'The International Society of Heart and Lung Transplantation Guidelines for the care of heart transplant recipients, August 2010' for support of transplanted heart.

1. Inj. Isoproterenol (1-10 mcg/min) i.v. (preferred due to chronotropic, inotropic, vasodilator activity), or
2. Inj. Dobutamine (1-10 mcg/kg/min) i.v. +/- Inj. Dopamine (1-10mcg/kg/min) i.v. or,
3. Inj. Isoproterenol (1-10 mcg/min) i.v. +/- Inj. Dopamine (1-10mcg/kg/min) i.v. or,
4. Inj. Milrinone (0.375-0.75mcg/kg/min) i.v. (inotropic, chronotropic, pulmonary>systemic vasodilator activity).

Vasoconstrictors such as Inj. Adrenaline (0.01-0.2 mcg/kg/min) i.v., Inj. Noradrenaline (0.01-0.3mcg/kg/min i.v., Inj. Phenylephrine i.v. can be used to maintain mean arterial pressure. Inj Vasopressin (0.03-0.1 Unit/min) i.v. or Inj. Methylene blue (1.5-2mg/kg) i.v. can be added to augment mean arterial pressure in case of vasoplegia resistant to the above vasoconstrictors.[38,44]

Inhaled nitric oxide (iNO) at 10-20 ppm or Inhaled prostacyclin can be started as a pulmonary vasodilator (if low systemic pressures preclude the use of intravenous Milrinone) and to attenuate Primary graft dysfunction.

To reduce myocardial work, inotrope infusions are started at a low dose, along with pacing at 50-60 beats/min if heart rate is low.

11.2. Ventilation

The lung is recruited followed by the use of Lung protective ventilation strategy with FiO2 of 1 (eventually titrated to 0.6), Tidal volume 6-8ml/kg, PEEP 5cm H2O, and avoid high airway pressure. Measures to reduce pulmonary vascular resistance such as hyperventilation, hyperoxia, hypocarbia, alkalosis, avoidance of atelectasis, and avoidance of alveolar hyperdistention are ensured.

Transoesophageal echocardiography (TOE) is used to ensure de-airing of the heart, watch for intra-cardiac thrombus, and assess flow across anastomotic sites. Mid-oesophageal 4-chamber view is used while weaning CPB to assess LV and RV systolic/diastolic function, atrial and ventricular size, and degree of tricuspid/mitral regurgitation). Right ventricular failure on TOE can be assessed by evidence of RV dilatation, reduced RV ejection fraction, reduced free-wall contractility, tricuspid regurgitation, left shift of inter-atrial septum.

Slow weaning from CPB is started once-

1. Heart is adequately reperfused.
2. Patient is rewarmed, urine output assessed.
3. Haemoglobin, Electrolytes, ABG, Blood glucose levels are corrected.
4. TOE findings are acceptable.
5. 12 lead ECG is shows regular sinus rhythm with no ST changes. Target heart rate of 100-110 beats/min is achieved. If donor heart rate is low, pacemaker is set to 90-110 beats/min, DOO mode)..
6. Inotropes, Vasoconstrictors, Pulmonary Vasodilators are optimised as per haemodynamics and TOE findings.

The PA Catheter is advanced into the pulmonary artery once CPB is weaned (pulmonary artery pressure, cardiac index and mixed venous oxygen saturation can be assessed).

Hemostasis is achieved, and drains are inserted. Hemodynamic stability is monitored during sternal approximation. Pacing is to be changed to DDD mode after chest closure.

11.3. Haemodynamic instability

can be due to RV and LV failure.

RV failure can be due to impaired RV systolic function or high PVR. RV failure management includes preload optimisation, PVR reduction, supporting RV contractility, maintain sinus rhythm and Atrio-ventricular synchrony, Ventilatory optimization.[45]

1. Preload is evaluated by response of i.v. fluid to RV dimensions (on TOE) and central venous pressure (CVP). An increase in CVP beyond 15 mmHg may cause RV dilatation and tricuspid regurgitation.
2. Use of inotrope (e.g. dopamine, adrenaline)
3. Hypotension reduces RV perfusion pressure; It is managed by noradrenaline (to target Mean Arterial Pressure >60 mmHg).
4. Strategies to reduce PVR include optimizing ventilatory strategy, use of pulmonary vasodilators (e.g. Inj. Milrinone, inhaled nitric oxide, inhaled prostacyclin).

11.4. LV systolic dysfunction and vasoplegia

LV dysfunction can be due to graft ischaemia, preexisting donor heart disease. Management includes inotropic

Table 7: Describes the possible post-operative complications in the ICU [30,36,37,46,47]

Complications in early post-operative period			
	Risk Factors	**Causes**	**Management**
Early Graft Dysfunction	-Older Donor Age -Recipient on High Inotropes -Long Warm ischaemia time	-Idiopathic - Right Ventricle pressure or Volume loading -Prolonged Graft Ischaemia time -Hyperacute rejection	-Support LV and RV Function.
Systemic Hypertension	-Vasculopathy	-Pain -Pre-operative hypertension -Cyclosporine	-Antihypertensive medication
Right Ventricular Failure	-Pre-transplant Pulmonary Hypertension -Reperfusion injury -Prolonged ischaemia time	-High pulmonary vascular resistance	-Reducing Pulmonary Vascular resistance -Optimizing Preload -Maintaining coronary perfusion pressure -Optimizing ventilatory settings with correction of acidosis and hypercarbia -Inhaled and intravenous pulmonary vasodilators
Haemodynamic Instability	-Allograft Antigen Sensitivity -Inflammatory Cytokines -Heart Failure medication (e.g. Angiotensin Converting Enzyme Inhibitors, Phosphodiesterase Inhibitors)	-Vasoplegia -Primary Graft Dysfunction -Hyperacute Rejection -High Pulmonary Vascular Resistance -Cardiac Tamponade	-Vasopressors, Inotropes -Mechanical Circulatory Support -Adequate immunosuppression coverage -Pulmonary Antihypertensives -Pericardial Drain repositioning/ Re-exploration
Cardiac Arrhythmias	-Electrolyte Disturbance -High inotropes -Acute rejection -Autonomic denervation -Graft dysfunction	- Bradyarrhythmia -Supraventricular arrhythmia -Ventricular arrhythmia	-Optimize Serum electrolytes (K, Mg) -External pacing -Epinephrine, Isoproterenol for bradyarrhythmia -Amiodarone for supraventricular arrhythmia -Lignocaine, and amiodarone for ventricular arrhythmia
Bleeding	-Previous heart surgery -Patient on Mechanical circulatory device -Cyanotic heart disease - Hepatic dysfunction	-Excessive haemodilution on Cardiopulmonary bypass -Prolonged surgical time -Hypothermia -Platelet dysfunction	-Rule out surgical cause -Normothermia -Assessment of haemoglobin, platelet, coagulation status -Transfusion Red cell concentrate, fresh frozen plasma, platelet, fibrinogen concentrate -Vitamin K -Desmopressin for acquired Von Willebrand Syndrome
Respiratory Failure	-Pre-operative mechanical ventilation -Frailty	-Left ventricular dysfunction -Pneumonia -Basal atelectasis -Pleural effusion	-Left heart support -Treatment of pulmonary infection -Drainage of pleural effusion -Adequate analgesia -Physiotherapy
Acute Kidney Injury	-Glomerular filtration rate <60ml/min/1.73m^2 -Body mass index >40kg/m^2 -Diabetes Mellitus -Surgery (Cardiopulmonary Bypass, Aortic Cross Clamp duration, Hypothermia, Prolonged graft ischaemia time) -Exposure to Blood scavenging system	-Graft Function -Arterial Hypotension -Venous Congestion -Nephrotoxic Drugs	-Maintain adequate preload -Maintain perfusion pressure -Maintain Haematocrit -Adjust Nephrotoxic Drugs -Renal Replacement Therapy
Infection	-Preoperative debilitation -Immunosuppression -Drug-induced leukopenia -Immunomodulation by viral infections -Diabetes	-Nosocomial and Donor-derived infection -Opportunistic infection -Community-acquired infection	-Screening for infections before transplant -Vaccination -Use of Cytomegalovirus-negative blood in susceptible recipients. -Standard precautions, barrier nursing, strict asepsis -Frequent surface disinfection -Pharmacologic prophylaxis

support with reduction in systemic vascular resistance, and mechanical support with IABP or ECMO.

Vasoplegia (defined as hypotension in presence of normal LVEF, normal or elevated Cardiac index, refractory to increased filling pressure or high-dose vasopressors). Vasoplegia occurs in about 29% of patients after heart transplant.[48] Predisposing factors are preoperative use of angiotensin-converting enzyme inhibitors, calcium channel blockers or amiodarone, presence of Left VAD or ECMO and prolonged Bypass time. Management includes vasopressors (Inj. noradrenaline and vasopressin) and Inj. methylene blue i.v.[44]

11.5. Mechanical circulatory support

Failure to wean from CPB due to borderline haemodynamics (MAP 65 mmHg, Cardiac Index <2L/min/m2, CVP >15mmHg) despite high inotropic support (e.g. Inj. adrenaline/noradrenaline >0.1-0.2 mcg/kg/min i.v.) is an indication for VA ECMO or temporary RV assist device in case of isolated RV dysfunction.[37]

12. Transfusion

Allosensitisation due to exposure to blood products is related to adverse outcomes post heart transplantation.[49] Hence, blood conservation strategies are to be implemented, transfusion is to be given sparingly, and leucodepleted blood products are to be used. Cytomegalovirus (CMV) antibody-negative donor blood is used if the patient is Negative for CMV antibodies.[37]

Once Heparin is reversed with Inj. Protamine. Inj Tranexamic Acid (total dose of 20mg/kg i.v. intraoperatively) is repeated post CPB.[50] Liver dysfunction, reoperations, VAD explant, and prolonged surgical time predispose patient to increased bleeding. Acquired von Willebrand syndrome in patients with VAD, respond to Inj. Desmopressin (0.3 mcg/kg i.v.).[51]

Packed RBCs, FFP, cryoprecipitate (or fibrinogen concentrate), and vitamin K use is guided by clinical assessment, preoperative coagulation status, amount of surgical dissection, CPB duration, and intraoperative values (of haemoglobin, platelet count, prothrombin time, activated partial thromboplastin time, point of care testing with thromboelastogram).

13. Post-operative Management

The goal of post-operative Intensive Care Unit (ICU) management includes maintaining haemodynamic stability, early extubation, maintenance of adequate analgesia, maintaining standard isolation and disinfection, antibiotic prophylaxis and immunosuppression, and monitoring for anticipated complications.

14. Future Directions[52]

There has been an increasing number of heart donations after circulatory death (DCD) with positive post-transplant results. These donations have also increased the donor pool.[53]

More data needs to be reviewed to assess the outcomes of Heart transplant from COVID-19-positive donor hearts.[54]

There is scope to increase the number of transplants in India by expanding government involvement, increasing public awareness for donation, public-private partnership for optimising transplantation process, infrastructure and skill building in government hospitals.

Studies in gene-edited pig-to-nonhuman primate (NHP) models, have provided encouraging data on pig heart survival with an anti-CD40m Antibody or an anti-CD154m Antibody immunosuppressive regimen.[55–58]

There is in vitro evidence suggesting a weaker immune response when triple gene-knockout (TKO) pig organs (i.e., expression of three pig glycan xenoantigens is deleted) are transplanted into humans.[59–61]

15. Conclusion

The science of heart transplantation has evolved from an experimental procedure to an established standard of care for end-stage heart failure.

The preoperative assessment, intraoperative management, and postoperative management of heart transplant patients require an immense team effort and a robust transplant program.

Management of heart transplant recipients from the Anaesthesia perspective is challenging due to a myriad of patient risk factors; and the urgent nature of surgery due to the unpredictable nature of donor heart availability.

The cardiac anaesthesiologist needs to be well versed with the modern changes in the field of Heart Transplant.

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17. Conflict of Interest

None.

References

1. Bozkurt B, Coats AJ, Tsutsui H, Abdelhamid M, Adamopoulos S, Albert N, et al. Universal definition and classification of heart failure: a report of the Heart Failure Society of America, Heart Failure Association of the European Society of Cardiology, Japanese Heart Failure Society and Writing Committee of the Universal Definition of Heart Failure: Endorsed by the Canadian Heart Failure Society, Heart Failure Association of India, Cardiac Society of Australia and New Zealand, and Chinese Heart Failure Association. *Eur J Heart Fail*. 2021;23(3):352–80.
2. Mcdonagh TA, Metra M, Adamo M, Gardner RS, Baumbach A, Böhm M, et al. ESC Scientific Document Group. 2021 ESC Guidelines for

the diagnosis and treatment of acute and chronic heart failure. *Eur Heart J*. 2021;42(36):3599–3726.
3. GBD 2017 Disease and Injury Incidence and Prevalence Collaborators. Global, regional, and national incidence, prevalence, and years lived with disability for 354 diseases and injuries for 195 countries and territories, 1990-2017: a systematic analysis for the Global Burden of Disease Study 2017. *Lancet*. 2017;392(10159):1789–1858.
4. Organ and Tissue Donation and Transplantation Activity Report 2022/23. Available from: https://nhsbtdbe.blob.core.windows.net/umbraco-assets-corp/30188/activity-report-2022-2023-final.pdf.
5. National data. Accessed on 21st may 2024. Available from: https://optn.transplant.hrsa.gov/data/view-data-reports/national-data.
6. Colvin M, Smith JM, Ahn Y, Skeans MA, Messick E, Bradbrook K, et al. OPTN/SRTR 2020 Annual Data Report: Heart. *Am J Transplant*. 2022;22(2):350–437.
7. Alraies MC, Eckman P. Adult heart transplant: indications and outcomes. *J Thorac Dis*. 2014;6(8):1120–8.
8. Singh TP, Cherikh WS, Hsich E, Lewis A, Perch M, Kian S, et al. Graft survival in primary thoracic organ transplant recipients: A special report from the International Thoracic Organ Transplant Registry of the International Society for Heart and Lung Transplantation. *J Heart Lung Transplant*. 2023;42(10):1321–33.
9. Organ Procurement and Transplantation Network (OPTN) and Scientific Registry of Transplant Recipients (SRTR). OPTN/SRTR 2022 Annual Data Report. U.S. Department of Health and Human Services, Health Resources and Services Administration. Accessed 10th June 2024. Available from: https://www.srtr.org/reports/optnsrtr-annual-data-report/.
10. Khush KK, Cherikh WS, Chambers DC, Harhay MO, Hayes D, Hsich E, et al. International Society for Heart and Lung Transplantation. The International Thoracic Organ Transplant Registry of the International Society for Heart and Lung Transplantation: Thirty-sixth adult heart transplantation report - 2019; focus theme: Donor and recipient size match. *J Heart Lung Transplant*. 2019;38(10):1056–66.
11. Lund LH, Edwards LB, Kucheryavaya AY, Benden C, Christie JD, Dipchand AI, et al. The registry of the International Society for Heart and Lung Transplantation: thirty-first official adult heart transplant report–2014; focus theme: retransplantation. *J Heart Lung Transplant*. 2014;33(10):996–1008.
12. Joshi Y, Villanueva J, Gao L, Hwang B, Zhao C, Doyle A, et al. Donation After Circulatory Death: A New Frontier. *Curr Cardiol Rep*. 2022;24(12):1973–81.
13. Chew HC, Iyer A, Connellan M, Scheuer S, Villanueva J, Gao L, et al. Outcomes of Donation After Circulatory Death Heart Transplantation in Australia. *J Am Coll Cardiol*. 2019;73(12):1447–59.
14. Jones DS, Sivaramakrishnan K. Transplant buccaneers: P.K. Sen and India's first heart transplant. *J Hist Med Allied Sci*. 1968;73:303–32.
15. Mittal CM. Profulla Kumar Sen: his contributions to cardiovascular surgery. *Tex Heart Inst J*. 2002;29(1):17–25.
16. Cardiovascular and Thoracic Surgery - King edward memorial hospital king edward memorial hospital [Internet]. [cited 2024 Jun 8]. Available from: https://www.kem.edu/public/cardiovascular-and-thoracic-surgery.
17. Jeevandan [Internet]. cited 2024 Jun 8. Available from: https://jeevandan.gov.in/ActsPage.htm.
18. Venugopal P. The first successful heart transplant in India. *Natl Med J India*. 1994;7:213–5.
19. Hand of God: Story of India's first successful heart transplant in a private hospital; 2015. Available from: https://www.thenewsminute.com/flix/hand-god-story-indias-first-successful-heart-transplant-private-hospital-35890.
20. Kalra A, Seth S, Hote MP, Airan B. The story of heart transplantation: from cape town to cape comorin. *J Pract Cardiovasc Sci*. 2016;2:120–5.
21. Shroff S, Mittal K, Navin S. Heart transplantation in India-looking back as we celebrate 25 years of the transplant law. *Indian J Thorac Cardiovasc Surg*. 2020;36(2):215–23.
22. Sankar NM, Kurian VM, Rajan S, Ninan B, Ajit M, Cherian KM. Heart-lung transplantation in India: initial experience. *Indian Heart J*. 2003;55(2):185–7.
23. Jose Chacko Periappuram [Internet]. cited 2024 Jun 8. Available from: https://en.wikipedia.org/wiki/Jose_Chacko_Periappuram.
24. Data for organ donation and transplantation (2013-2022). Available from: https://notto.mohfw.gov.in/WriteReadData/Portal/News/814_1_2013_to_2022.pdf.
25. Birati EY, Jessup M. Left Ventricular Assist Devices in the Management of Heart Failure. *Card Fail Rev*. 2015;1(1):25–30.
26. Ahmed T, Jain A. Heart Transplantation (Internet). Treasure Island (FL): StatPearls Publishing; 2023. Available from: https://www.ncbi.nlm.nih.gov/books/NBK557571/.
27. Jonge ND, Kirkels JH, Klöpping C, Lahpor JR, Caliskan K, Maat AP, et al. Guidelines for heart transplantation. *Neth Heart J*. 2008;16(3):79–87.
28. Allocation criteria for heart, lung & heart-lung. Available from: https://notto.mohfw.gov.in/WriteReadData/Portal/News/418_1_29082016FinalHeartAllocationPolicy.pdf.
29. Adult heart allocation. Available from: https://optn.transplant.hrsa.gov/professionals/by-organ/heart-lung/adult-heart-allocation/.
30. Baiocchi M, Benedetto M, Agulli M, Frascaroli G. Anesthesia and Intensive Care Management for Cardiac Transplantation. In: Loforte A, Montalto A, Amarelli C, editors. Heart Transplantation. IntechOpen; 2018.
31. Kar SK, Mishra P. An Overview of Anesthesia Practices for Heart Transplant in India. *Acta Sci Pharm Sci*. 2019;3(12):64–75.
32. Mehra MR, Kobashigawa J, Starling R, Russell S, Uber PA, Parameshwar J, et al. Listing criteria for heart transplantation: International Society for Heart and Lung Transplantation guidelines for the care of cardiac transplant candidates–2006. *J Heart Lung Transplant*. 2006;25(9):1024–42.
33. Mehra MR, Canter CE, Hannan MM, Semigran MJ, Uber PA, Baran DA, et al. International Society for Heart Lung Transplantation (ISHLT) Infectious Diseases, Pediatric and Heart Failure and Transplantation Councils. The 2016 International Society for Heart Lung Transplantation listing criteria for heart transplantation: A 10-year update. *J Heart Lung Transplant*. 2016;35(1):1–23.
34. Velleca A, Shullo MA, Dhital K, Azeka E, Colvin M, Depasquale E, et al. The International Society for Heart and Lung Transplantation (ISHLT) guidelines for the care of heart transplant recipients. *J Heart Lung Transplant*. 2023;42(5):1–141.
35. Yuki K. Anesthetic Management for Heart Transplantation in Adults with Congenital Heart Disease. *Transl Perioper Pain Med*. 2020;7(3):248–52.
36. Neethling E, Garijo JM, Mangalam T, Badiwala MV, Billia P, Wasowicz M, et al. Intraoperative and Early Postoperative Management of Heart Transplantation: Anesthetic Implications. *J Cardiothorac Vasc Anesth*. 2019;34(8):2189–2206.
37. Edwards S, Allen S, Sidebotham D. Anaesthesia for heart transplantation. *BJA Educ*. 2021;21(8):284–91.
38. Costanzo MR, Dipchand A, Starling R, Anderson A, Chan M, Desai S. International Society of Heart and Lung Transplantation Guidelines. The International Society of Heart and Lung Transplantation Guidelines for the care of heart transplant recipients. *J Heart Lung Transplant*. 2010;29(8):914–56.
39. Shore-Lesserson L, Baker RA, Ferraris V, Greilich PE, Fitzgerald D, Hammon RP, et al. STS/SCA/AmSECT Clinical Practice Guidelines: Anticoagulation during Cardiopulmonary Bypass. *J Extra Corpor Technol*. 2018;50(1):5–18.
40. Chen Y, Phoon P, Hwang NC. Heparin Resistance During Cardiopulmonary Bypass in Adult Cardiac Surgery. *J Cardiothorac Vasc Anesth*. 2022;36(11):4150–60.
41. Khoshbin E, Schueler S. Pre-transplant ventricular assist device explant. *Ann Cardiothorac Surg*. 2018;7(1):160–8.
42. MMCTS. Orthotopic heart transplantation: the bicaval technique (Internet). Available from: https://mmcts.org/tutorial/891.
43. Fischer S, Glas KE. A review of cardiac transplantation. *Anesthesiol Clin*. 2013;31(2):383–403.

44. Muhammad R, Dharmadjati BB, Mulia EPB, Rachmi DA. Vasoplegia: Mechanism and Management Following Cardiopulmonary Bypass. *Eurasian J Med*. 2022;54(1):92–100.
45. Haddad F, Doyle R, Murphy DJ, Hunt SA. Right ventricular function in cardiovascular disease, part II: pathophysiology, clinical importance, and management of right ventricular failure. *Circulation*. 2008;117(13):1717–31.
46. Simsch O, Gromann T, Knosalla C, Huebler M, Hetzer R, Lehmkuhl H. The intensive care management of patients following heart transplantation at the Deutsches Herzzentrum Berlin. *Appl Cardiopulm Pathophysiol*. 2011;23(3).
47. Nesseler N, Mansour A, Cholley B, Coutance G, Bouglé A. Perioperative Management of Heart Transplantation: A Clinical Review. *Anesthesiology*. 2023;139(4):493–510.
48. Kumar N, Fitzsimons MG, Iyer MH, Essandoh M, Kumar JE, Dalia AA, et al. Vasoplegic syndrome during heart transplantation: A systematic review and meta-analysis. *J Heart Lung Transplant*. 2024;43(6):931–43.
49. Habal MV. Current Desensitization Strategies in Heart Transplantation. *Front Immunol*. 2021;12:702186.
50. Faraoni D, Levy JH. Optimal Tranexamic Acid Dosing Regimen in Cardiac Surgery: What Are the Missing Pieces? *Anesthesiology*. 2021;134(2):143–6.
51. Franchini M, Mannucci PM. Acquired von Willebrand syndrome: focused for hematologists. *Haematologica*. 2020;105(8):2032–7.
52. Cooper DKC, Cozzi E. Clinical Pig Heart Xenotransplantation—Where Do We Go From Here? *Transpl Int*. 2024;37:12592.
53. Siddiqi HK, Trahanas J, Xu M, Wells Q, Farber-Eger E, Pasrija C, et al. Outcomes of Heart Transplant Donation After Circulatory Death. *J Am Coll Cardiol*. 2023;82(15):1512–20.
54. Kim ST, Iyengar A, Helmers MR, Weingarten N, Rekhtman D, Song C, et al. Outcomes of COVID-19-Positive Donor Heart Transplantation in the United States. *J Am Heart Assoc*. 2023;12(14):e029178.
55. Längin M, Mayr T, Reichart B, Michel S, Buchholz S, Guethoff S, et al. Consistent Success in Life-Supporting Porcine Cardiac Xenotransplantation. *Nature*. 2018;564(7752):430–3.
56. Goerlich CE, Griffith B, Hanna P, Hong SN, Ayares D, Singh AK, et al. The Growth of Xenotransplanted Hearts Can Be Reduced With Growth Hormone Receptor Knockout Pig Donors. *J Thorac Cardiovasc Surg*. 2023;165(2):e69–81.
57. Cleveland DC, Jagdale A, Carlo WF, Iwase H, Crawford J, Walcott GP, et al. The Genetically Engineered Heart as a Bridge to Allotransplantation in Infants: Just Around the Corner? *Ann Thorac Surg*. 2021;114(2):536–44.
58. Mohiuddin MM, Goerlich CE, Singh AK, Zhang T, Tatarov I, Lewis B, et al. Progressive Genetic Modifications of Porcine Cardiac Xenografts Extend Survival to 9 Months. *Xenotransplantation*. 2022;29(3):e12744.
59. Singh AK, Goerlich CE, Shah AM, Zhang T, Tatarov I, Ayares D, et al. Cardiac Xenotransplantation: Progress in Preclinical Models and Prospects for Clinical Translation. *Transpl Int*. 2022;35:10171.
60. Estrada JL, Martens G, Li P, Adams A, Newell KA, Ford ML, et al. Evaluation of Human and Non-Human Primate Antibody Binding to Pig Cells Lacking GGTA1/CMAH/β4GalNT2 Genes. *Xenotransplantation*. 2015;22(3):194–202.
61. Yamamoto T, Hara H, Iwase H, Jagdale A, Bikhet MH, Morsi MA, et al. The final obstacle to successful pre-clinical xenotransplantation? *Xenotransplantation*. 2020;27(5):e12596.

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