Chapter

36 ORGAN TRANSPLANTATION

Randolph H. Steadman and Victor W. Xia

Patients waiting for a transplantable organ share a hope for the future that is predicated on the availability of an organ donor. Donor death must be declared prior to organ procurement. Donation after brain death (DBD) is the most common setting in which donation occurs.[1] Organ shortages have led to donation after cardiac death (DCD).[2] The ethical considerations related to DCD donation are challenging, yet DCD donation is increasing in response to the national organ shortage.[3,4]

CONSIDERATIONS FOR ORGAN TRANSPLANTATION

Because of the shortage of available organs not all potential recipients on the waiting list survive long enough to undergo a transplant procedure. Those who do typically wait a year or more. Prelisting assessments may be outdated by the time an organ is identified, and supplemental testing may be indicated. This testing may necessitate a deferral of the scheduled transplant, which must be weighed against the risk of further deterioration that can preclude transplantation. Untreated systemic infection, incurable malignancy, untreated substance abuse, and the lack of sufficient social support to comply with posttransplant care can preclude transplantation.

Once the decision is made to proceed with transplantation, coordination between the donor procedure and multiple recipient hospitals may be involved. Because not all donor organs are suitable for transplantation, the recipient operation should not begin until visual or biopsy-based confirmation of organ suitability has been made. During the time between the identification of the donor and the procurement surgery, the recipient's latest laboratory values should be ascertained. If necessary, dialysis can be performed. The anesthetic plan should be reviewed with the patient and the family, questions and concerns are addressed, and the patient's consent is obtained.

Box 36.1 Kidney Transplantation Facts

- The kidney is the most frequently transplanted solid organ.
- More than 10,000 deceased donor and 6000 live donor kidney transplant procedures are performed annually in the United States.
- Five-year posttransplantation survival rates are 91% for recipients of live donor grafts, 83% for standard (non-ECD) deceased donor recipients, and 70% for recipients of grafts from ECDs.
- Transplantation improves survival rate over that achieved with dialysis, which carries a 20% annual mortality risk.

ECD, Extended criteria donor.
From Annual Report of the U.S. Organ Procurement and Transplantation Network and the Scientific Registry of Transplant Recipients: Transplant Data 1998-2007. Rockville, MD: U.S. Department of Health and Human Services, Health Resources and Services Administration, Healthcare Systems Bureau, Division of Transplantation; 2008.

KIDNEY TRANSPLANTATION

Kidney transplantation confers a survival advantage over dialysis for the management of renal failure.[5] The best organ survival occurs from transplantation with grafts (kidney) from living donors, but even kidneys from marginal deceased donors confer a survival advantage over continued dialysis (Box 36.1). Marginal or extended criteria donor (ECD) grafts have lower graft survival rates than standard grafts. The recently implemented kidney donor risk index (KDRI) provides a more detailed assessment of risk associated with donor kidneys than the non-ECD/ECD classification.[6] Donor factors in the KDRI include older, hypertensive, and diabetic donors, and grafts with a prolonged duration of cold or warm ischemia, as seen with long preservation times and DCD donors, respectively.

Preoperative Assessment

Because of the shortage of deceased donor grafts, the number of candidates on the waiting list continues to increase (also see Chapter 13). The median time on the waiting list in the United States is longer than 5 years for recipients of deceased donor grafts.[7] This makes it challenging to maintain an up-to-date pretransplant assessment. Currently one third of kidney transplants are living-related, which facilitates scheduling preoperative evaluation and significantly shortens waiting time. Almost all living donations are performed laparoscopically; few are converted to open procedures.[7]

Diabetes is the most common cause of end-stage renal disease, followed by hypertension, and glomerulonephritis (Box 36.2). These three causes account for over two thirds of the cases of renal failure. Patients with these conditions should be medically managed to achieve treatment goals while on the waiting list.

Box 36.2 Kidney Transplant Recipient: Preoperative Assessment

Cardiovascular
- Ischemic heart disease
- Congestive heart failure
- Hypertension

Diabetes
- Hyperkalemia
- Acidosis
- Anemia
- Dialysis history

Although cardiovascular disease is the leading cause of death in patients receiving dialysis, cardiovascular risk factors are often undertreated.[8] After transplant, the cardiovascular risk diminishes from a tenfold to a twofold increase compared to that of normal patients. Accordingly, the preoperative assessment should focus on screening for ischemic heart disease and management of hypertension, diabetes, and dyslipidemia. Ischemic heart disease may be silent, particularly in diabetic patients. As a result of preexisting vasodilatation stress, echocardiography is probably superior to thallium imaging in predicting postoperative cardiac events, although false positive and false negative findings occur with both techniques.[9] Coronary angiography, accompanied by therapeutic intervention for significant lesions, should be considered in patients with reversible cardiac ischemia or in those with significant risk.

Congestive heart failure is prevalent in dialysis patients but, in the absence of ischemic heart disease, does not preclude safe transplantation. Ejection fraction typically improves after transplantation. The preoperative focus is on optimal medical management of heart failure and maintenance of intravascular fluid balance.

Anemia may increase cardiovascular risk, particularly in patients with ischemic heart disease. A hemoglobin level of 12 g/dL is sufficient; higher hemoglobin concentrations may increase the risk of thrombotic events. Erythropoietin, when used to correct anemia to levels of 12 g/dL or less, lessens the risk of blood transfusion (see Chapter 24).

Hyperkalemia is common in patients with renal insufficiency and may be associated with increased risks during transplant surgery, particularly during reperfusion. However, mild increases in potassium may reflect normal homeostasis for renal failure, and potassium levels of 5.0 to 5.5 mEq/L are acceptable in this population. Dialysis-dependent patients may benefit from dialysis immediately prior to transplantation; however, a reduced intravascular central volume may offset the benefits of reduced potassium levels.

Intraoperative Management

Donor kidneys are usually implanted in the iliac fossa. Vascular anastomoses are most frequently to the external iliac artery and vein, and the ureter is anastomosed

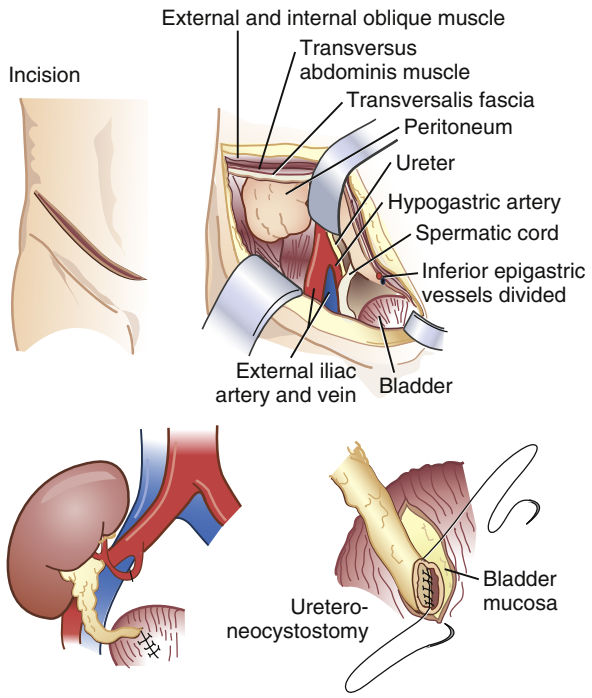

Fig. 36.1 Kidney recipient operation. (From Townsend CM Jr, Beauchamp RD, Evers BM, Mattox KL, eds. *Sabiston Textbook of Surgery.* 18th ed. Philadelphia: Saunders Elsevier; 2007, used with permission.)

directly to the bladder (Fig. 36.1). Chronic renal disease can affect drug excretion via the kidney but also through changes in plasma protein binding or hepatic metabolism. When the protein binding is diminished the free fraction of the drug is increased. This results in an increase in the volume of distribution and the clearance. The net effect for the unbound fraction is similar to that in normal patients.

Some drugs require particular caution when administered in patients with renal failure.[1] They include neuromuscular blocking (NMB) drugs (also see Chapter 11) and certain opioids (also see Chapter 9). Long-acting NMB drugs, which are excreted via the kidneys (e.g., pancuronium), are best avoided. Vecuronium and rocuronium may have a prolonged action in patients with renal failure. Cisatracurium's duration of action is more predictable because of spontaneous breakdown (also see Chapter 11). Although atracurium undergoes similar elimination, it is less potent than cisatracurium, so its breakdown product, laudanosine, is found in higher concentrations. Laudanosine's theoretical potential to cause seizures has never been clinically important.

The 6-glucuronide metabolite of morphine has clinical activity that can result in a prolonged duration of action. Meperidine should be avoided because of the seizure-inducing potential of its metabolite, normeperidine.

Inhaled anesthetics can be used in renal failure patients. Although sevoflurane's metabolite, compound A, is nephrotoxic in rats, similar effects have not been seen in humans. Serum fluoride concentrations of 30 μmol occur in humans after sevoflurane, but do not produce renal damage. Isoflurane is metabolized to fluoride, but the extent of metabolism is so small that fluoride levels are negligible. Desflurane is not contraindicated in renal failure; but like the other volatile anesthetics, it produces a decrease in renal blood flow and glomerular filtration rate in a dose-dependent manner.

Intravascular fluid balance should be maintained in patients undergoing kidney transplantation. Typically crystalloid is used for this purpose with colloids preferred by some centers. In an intensive care unit (ICU) population (also see Chapter 41), balanced salt solutions (e.g., lactated Ringer solution, Plasma-Lyte) are preferred over hyperchloremic crystalloids such as normal saline. These balanced salt solutions are associated with a lower incidence of acute kidney injury and a reduced need for renal replacement.[10] Paradoxically, their effect on serum potassium levels is less than that of potassium-free hyperchloremic solutions, which are more likely to increase serum blood potassium concentrations by generating a hyperchloremic acidosis. Albumin is the typical colloid of choice; hydroxyethyl starch solution is associated with a more frequent risk of acute kidney injury.[11]

Monitoring arterial blood pressure via an arterial catheter is avoided in some centers in order to preserve arterial access for dialysis, whereas other centers use arterial monitoring regularly in an aging recipient population with increasingly common comorbid conditions. Central venous pressure (CVP) monitoring is now recognized as a poor monitoring method of preload and fluid responsiveness.[12] Placement of a central intravenous line should be reserved for medications that require administration into a high flow vein such as rabbit antithymocyte globulin, an immunosuppression induction drug. Induction of immunosuppression is increasingly common as efforts to increase the living donor pool include use of unrelated living donors, nondirected donors, and donor exchange programs.

Delayed graft function and acute tubular necrosis can lead to renal replacement therapy after transplantation. The factors responsible include donor hemodynamics, graft warm ischemia, and recipient hemodynamics. Adequate hydration reduces the incidence of acute tubular necrosis. There are few data to support the intraoperative use of diuretics, and there is considerable variability between surgeons regarding the intraoperative use of diuretics.[13] Although of unproven benefit in preventing acute kidney injury in a general perioperative population, administration of osmotic diuretics, such as mannitol, during transplantation may be helpful.[14]

Postoperative Management

Maintaining renal perfusion is an important consideration and is best accomplished by maintaining an adequate intravascular volume. Dopamine, large-dose diuretics, and osmotic diuretics are of no proven benefit in the postoperative period. Postoperative analgesia can be achieved by epidural infusion, although many health care facilities prefer intravenously administered patient-controlled analgesia with fentanyl or morphine (also see Chapter 40). Nonsteroidal antiinflammatory drugs should be avoided.

LIVER TRANSPLANTATION

The liver is second to the kidney as the most frequently transplanted solid organ. Patients with liver failure have no alternatives to liver transplantation.[1] The median time to transplant for waiting list candidates decreased significantly, from 14 months in 2012 to just over a month in 2013, owing to within-region sharing of liver grafts for the highest acuity recipients (those with model for end-stage liver disease [MELD] scores of 35 or more). The MELD score is used to allocate grafts based upon the recipient's 90-day mortality risk in the absence of transplantation. International normalized ratio (INR) of prothrombin time, creatinine, and bilirubin are used to derive the MELD score. The most common indication for liver transplantation in the United States is hepatitis C virus, followed by alcoholic liver disease, cholestatic disease, and malignancy. Combined, these diagnoses account for 70% of candidates who are on the waiting list. New antiviral agents for hepatitis C, introduced in 2013, are expected to reduce, if not eliminate, transplants for this diagnosis in the future. Nonalcoholic steatohepatitis (NASH), a diagnosis associated with metabolic syndrome and obesity, is expected to become an increasingly prevalent cause leading to transplantation in the coming years.

An ongoing shortage of donors has lead to the increased use of marginally viable grafts, defined as organs from elderly donors; DCD donors; donors with steatotic livers, obesity, malignancy, prolonged ICU stays, bacterial infection, or high-risk lifestyle; donors on multiple vasopressor infusions; or those who had suffered cardiac arrest.[15]

Preoperative Assessment

Over 75% of transplant recipients are older than 50 years, compared to 63% 10 years ago (also see Chapter 13). A higher percentage are hospitalized and have comorbid conditions. Liver transplant candidates have many symptoms ranging from fatigue to multiple organ failure (Box 36.3). Encephalopathy, common in end-stage liver disease (ESLD), can lead to sensitivity to sedative and analgesic medications, increased risk of aspiration of gastric contents, and the need for endotracheal intubation to protect the airway.

Box 36.3 Liver Transplant Recipient: Preoperative Assessment

- Neurologic
  - Encephalopathy
  - Cerebral edema (acute liver failure)
- Cardiovascular
  - Hyperdynamic circulation
  - Cirrhotic cardiomyopathy
  - Portopulmonary hypertension
- Pulmonary
  - Restrictive lung disease
  - Ventilation-perfusion mismatch
  - Intrapulmonary shunts
  - Hepatopulmonary syndrome
- Gastrointestinal
  - Portal hypertension
  - Variceal bleeding
  - Ascites
- Renal/metabolic
  - Hepatorenal syndrome
- Acid-base abnormalities
  - Hematologic
  - Coagulopathy
  - Anemia
- Musculoskeletal
  - Muscle atrophy

The pretransplant cardiac evaluation includes an assessment for ischemic heart disease and screening for portopulmonary hypertension (PPHTN). Dobutamine stress echocardiography and nuclear scans are common screening tests to rule out coronary artery disease; however, they are associated with both false positive and false negative results.[9] In older patients with diabetes, multiple risk factors, or a history of coronary disease, left-sided heart catheterization may be indicated (also see Chapters 25 and 35). More than two thirds of ESLD patients have a hyperdynamic circulation characterized by a high cardiac output and low systemic vascular resistance (SVR), most likely because of circulating vasoactive substances not cleared by the liver. This hyperdynamic state can be confused with sepsis and is exacerbated by graft reperfusion.

Resting echocardiography is the test of choice in screening for PPHTN. An estimated right ventricular systolic pressure less than 50 mm Hg by echocardiography rules out significant PPHTN. Right-sided heart catheterization is indicated if estimated right ventricular pressure exceeds 50 mm Hg. The definitive diagnosis of PPHTN is made when the mean pulmonary artery (PA) pressure is more than 25 mm Hg in the presence of an increased transpulmonary gradient (mean PA minus PA occlusion pressure > 12) and an increased pulmonary vascular resistance (>3 Wood units, or >240 dynes/s/cm^5). Mean PA pressures higher than 35 mm Hg are associated with a perioperative mortality rate of 50%, and treatment prior to transplant should be considered.

Hepatopulmonary syndrome (resting and breathing room air Po_2 < 70 mm Hg in the presence of an intrapulmonary shunt on bubble echocardiography) resolves after transplantation; however, Pao_2 levels less than 50 mm Hg while breathing room air are associated with increased acuity, longer postoperative hospital stays, and, in some studies, a higher postoperative mortality rate.

Renal disease is common in patients who present for liver transplantation. If not long-standing, hepatorenal syndrome may resolve after transplantation. Prior to transplantation, excessive intravascular volume, acidosis, or hyperkalemia may necessitate renal replacement therapy. The coagulopathy of ESLD is multifactorial and requires correction in the presence of active bleeding.

Acute liver failure (ALF) accounts for approximately 5% of liver transplants. ALF is distinct from chronic liver disease because of the potential for cerebral edema, which is the most common cause of death in ALF.[16] Cerebral edema is managed similarly to other causes of increased intracranial pressure (also see Chapter 30). The cause of ALF often predicts whether spontaneous recovery without transplant is likely. Approximately 25% of ALF patients undergo liver transplantation; survival rate in those receiving transplants is similar to posttransplant survival rate in patients with chronic liver disease.

Intraoperative Management

Intraoperative management requires a consideration of the effects of liver failure on drug metabolism. Preoperative anxiolytic medication should be used sparingly in patients with a history of encephalopathy. The chosen anesthetic should maintain SVR. The intermediate duration NMB drugs metabolized by the liver can have a prolonged duration of action; however, after reperfusion, evidence of liver function typically occurs and metabolism of these drugs improves. Alternatively cisatracurium, which undergoes Hofmann elimination, can be selected to avoid these concerns. Seizures can also be caused by an accumulation of normeperidine, so meperidine should be avoided. The metabolite of morphine, 6-glucuronide morphine, can accumulate and cause a prolonged effect. Fentanyl and the other synthetic opioids are safe choices. Volatile anesthetics have similar, mild effects on hepatic blood flow. Sevoflurane undergoes metabolism by the liver, but the metabolite, compound A, is not toxic to the liver or kidneys in humans.

Intraoperative monitoring varies among medical centers (Box 36.4). An arterial line is placed, followed by a central venous catheter (CVC) and pulmonary artery catheter (PAC), or CVC alone. Continuous cardiac output measurement from arterial waveform analysis may not accurately reflect cardiac output in liver recipients as a result of low SVR, high cardiac output, and vasopressor administration. Stroke volume and pulse pressure variation, although more accurate than CVP monitoring for predicting fluid responsiveness, are less accurate during mechanical ventilation with smaller tidal volumes (<8 mL/kg) and in the presence of cardiac arrhythmias.[17] Transesophageal echocardiography (TEE) is often used, which may obviate the need for PAC monitoring in the operating room. TEE represents the gold standard for cardiac preload monitoring; however, interpretation is operator dependent and monitoring into the postoperative period is not feasible.

Box 36.4 Liver Transplantation: Unique Aspects of Case Preparation

Transfusion
Red blood cells: 6-10 units for adults
Fresh frozen plasma: 6-10 units for adults
Rapid infusion device

Medication
Vasopressors: phenylephrine, epinephrine (10 and 100 μg/mL), vasopressin
Calcium chloride: for infusion and bolus
Insulin: for infusion (poststeroid immunosuppression and/or hyperkalemia unresponsive to diuretics)

Monitors
Arterial line
Central venous pressure catheter
Pulmonary artery catheter
Transesophageal echocardiography

Venovenous bypass is used in some medical facilities to attenuate the effects of inferior vena cava (IVC) clamping on intravascular volume; however, it has risks and adds to the length of the procedure.

The operation is divided into three phases: preanhepatic, anhepatic, and neohepatic. In the preanhepatic phase dissection and preparation for the native hepatectomy occur. This phase is associated with blood loss, particularly in the presence of varices and prior abdominal surgery. Vascular isolation of the native liver (cross-clamping of the IVC, portal vein, and hepatic artery) begins the anhepatic phase. Excision of the native liver occurs next and is followed by implantation of the donor graft. The implantation involves anastomoses of the suprahepatic IVC, the infrahepatic IVC, and the portal vein (Fig. 36.2). An alternative "piggyback" technique involves anastomosis of the donor hepatic veins to the recipient vena cava, followed by portal anastomosis. The anhepatic period is typically quiescent from a hemodynamic perspective. Reperfusion follows portal anastomoses and begins the neohepatic period. Reperfusion is the most precarious event during the procedure because of the release of cold, acidotic effluent from the graft and lower extremities (Box 36.5). *Reperfusion syndrome* is characterized by a decrease in systemic blood pressure and SVR.[18] The portal effluent contains vasoactive peptides that reduce SVR and can increase pulmonary resistance. Hyperkalemia can be life threatening. If

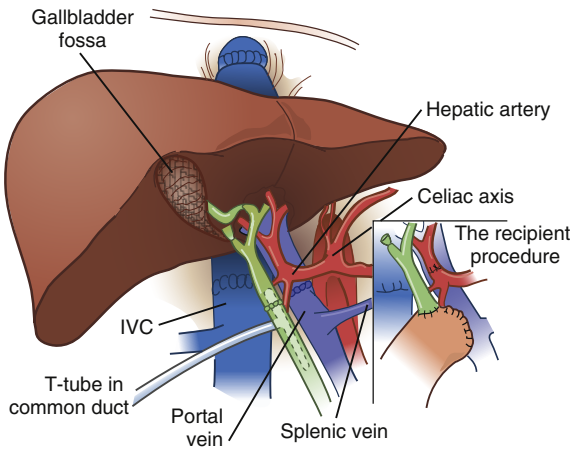

Fig. 36.2 Liver recipient operation. *IVC*, Inferior vena cava. Illustrated are the anastomoses of the donor and recipient suprahepatic IVC, infrahepatic IVC, portal vein, hepatic artery, and duct-to-duct biliary anastomosis, which can be performed with or without T-tube placement. Alternatively *(inset)*, in the presence of disease of the bile duct biliary drainage is via a choledochojejunostomy. (From Townsend CM Jr, Beauchamp RD, Evers BM, Mattox KL, eds. *Sabiston Textbook of Surgery.* 18th ed. Philadelphia: Saunders Elsevier; 2007, used with permission.)

Box 36.5 Liver Transplantation: Treatment for the Physiologic Changes of Reperfusion

- *Hyperkalemia*: calcium, bicarbonate, insulin, and glucose
- *Acidosis*: bicarbonate, other buffers such as tris (hydroxymethyl) aminomethane
- *Decreased SVR*: α-agonists
- *Hypothermia*: warm saline peritoneal lavage

SVR, Systemic vascular resistance.

hyperkalemia is a concern, dialysis is helpful if started early in the preanhepatic period. Insulin is effective if given at least 10 to 15 minutes prior to reperfusion; infusions are preferred to repeated bolus dosing. Calcium given immediately prior to reperfusion blunts the effect of hyperkalemia on the myocardium. α-Adrenergic agonists and alkalizing drugs may be required to maintain SVR and pH, respectively.

During the neohepatic phase, fibrinolysis can occur resulting in ongoing oozing due to microvascular bleeding. If fibrinolysis is not self-limited, antifibrinolytic drugs can be administered. Metabolic acidosis, which worsens during the anhepatic phase and peaks after reperfusion, should improve when the liver starts functioning. Additional signs of liver function include increased core temperature and decreasing calcium requirement (indicating citrate metabolism by the liver). On occasion oliguric patients with hepatorenal syndrome may show an increase in urine output in the operating room.

Postoperative Management

Posttransplant patient survival rates are 85% to 90% at 1 year and 72% to 78% after 5 years. Recipients of grafts from living donors have the most success with 1- and 5-year posttransplant survival rates. Thrombosis of the hepatic artery in the early postoperative period usually necessitates retransplantation. Infection is a major threat to survival in the initial months after transplant.

HEART TRANSPLANTATION

Heart transplantation is the definitive treatment for patients with end-stage heart disease. Currently, the three most common indications for heart transplantation are idiopathic dilated cardiomyopathy, ischemic heart disease, and congenital heart disease, which account for more than 90% of the transplants.[19]

Preoperative Evaluation

Although patients undergo extensive multidisciplinary evaluation before being listed, a detailed preanesthetic evaluation is often challenging owing to the urgent nature of the surgery, the complex clinical presentation, and multiple comorbid conditions.[20] Many patients require inotropic drugs or mechanical support at the time of heart transplantation. Preoperative evaluation should focus on current cardiac status, medications (particularly the need for inotropic and anticoagulant drugs), and mechanical support such as intra-aortic balloon pump or ventricular assist device. The patients should not have severe, irreversible pulmonary hypertension or an active infectious disease. For patients with multiple organ failure, combined heart transplantation with other organs (e.g., lung, kidney, liver) may be considered (also see Chapter 13).

Intraoperative Management

In addition to standard monitors, invasive hemodynamic monitors (arterial lines, CVCs, and PACs) are routinely inserted for heart transplantation.[21] The right internal jugular vein remains a preferred site despite a concern that it may jeopardize postoperative biopsies. The PAC needs to be withdrawn to the jugular vein before the native heart is excised. Alternatively, the PAC is inserted at the central venous position and is advanced after the donor heart is implanted. In some institutions, a PAC with capability of continuous monitoring of mixed venous O_2 saturation and cardiac output is also used. TEE plays an important role in assessing intravascular volume status, contractility, and valvular function, while monitoring for thromboembolism (also see Chapter 25).

Box 36.6 Heart Transplantation: Perioperative Goals

- Maintain systemic blood pressure to maintain coronary filling
- Optimize preload
- Reduce afterload to improve ejection fraction
- Avoid pulmonary vasoconstriction
  - Maintain oxygenation
  - Avoid hypercapnia
  - Avoid high tidal volumes
  - Correct acid-base abnormalities
- Support contractility
  - Pharmacologic drugs
  - Intra-aortic balloon pump
  - Assist devices

Patients who are having a heart transplant often have a full stomach due to the urgency of the procedure; therefore, a rapid sequence induction of anesthesia is needed. The choice of anesthetic is dictated by the patient's cardiac status. A failing heart is dependent on preload and sensitive to afterload. Even small changes in venous return, vascular resistance, rhythm, heart rate, and contractility can lead to hemodynamic collapse. Anesthetics with minimal hemodynamic impact are often chosen to induce anesthesia. Etomidate is a reasonable selection. Maintenance of anesthesia is often achieved by administration of a combination of a volatile anesthetic and an opioid. A large-dose opioid technique can be used as well. Nitrous oxide is usually avoided as cardiac suppression can be seen in heart transplant patients and is presumably due to catecholamine store depletion and β-adrenergic receptor downregulation.

Management goals during heart transplantation are dictated by the underlying congestive heart failure and the need to avoid conditions that increase PA pressure (Box 36.6). Weaning from cardiopulmonary bypass is similar to any other cardiac case. Patients are rewarmed. Acid-base and electrolytes should be in the normal range, the lungs are ventilated with 100% oxygen, and the cardiac chambers are free of air.

Several intraoperative issues are unique to heart transplantation. First, the transplanted heart is denervated and bradycardia can occur following reperfusion. The heart rate response to hemodynamic changes is absent and drugs acting indirectly on the heart are ineffective. Bradycardia can be treated by pacing (usually 90 to 110 beats/min) or chronotropic drugs such as isoproterenol. Second, failure to wean from cardiopulmonary bypass is often caused by right-sided heart failure. Several possible mechanisms are related to right-sided heart failure during heart transplantation: preexisting pulmonary hypertension can be worsened during reperfusion of the donor heart, and the right ventricle is particularly prone to ischemia/reperfusion injury. The primary treatment goals for right-sided heart failure during heart transplantation are to increase contractility of the right ventricle and decrease PA resistance. Failure to respond may necessitate mechanical right ventricular support. Worsening pulmonary hypertension during heart transplantation is multifactorial. An increase in cardiac output, pulmonary vessel spasm, and blood or air embolism are all possible causes. Adequate ventilation and oxygenation, with avoidance of hypoxia and hypercarbia, can prevent an increase in pulmonary vasculature resistance. Treatment of pulmonary hypertension with nonselective vasodilators such as nitroglycerin and sodium nitroprusside can decrease SVR and result in systemic hypotension. Selective drugs such as inhaled nitric oxide, aerosolized iloprost (a carbacyclin analog of prostaglandin I_2), and sildenafil (inhaled or infused) may be helpful.

Postoperative Management

Postoperative management targets adequate oxygenation, ventilation, intravascular volume, pulmonary and systemic pressures, coagulation, and body temperature. Extubation of the trachea is considered when stable hemodynamics and adequate spontaneous ventilation have been achieved. Some patients require permanent pacemaker implantation because of the loss of sinus node function.[21] Most patients require inotropic and chronotropic support in the first few days following heart transplant. Posttransplant bleeding and a nonfunctional graft are life threatening and need to be diagnosed and managed emergently.

LUNG TRANSPLANTATION

Chronic obstructive lung disease and interstitial lung disease are two common indications for adult lung transplantation.[22] In children, cystic fibrosis is the most common indication for lung transplantation. The choice of transplant type (single, sequential, double lung) is dependent on the surgeon's preference and the nature and severity of disease. Each operative type requires slightly different anesthetic setup and intraoperative management.

Preoperative Evaluation

Preoperative evaluation should focus on the severity of lung disease, the baseline function of other vital organs, the airway, and interval changes since the last examination (also see Chapter 13).[23] The preoperative administration of anxiolytic drugs should be performed with caution, as too much sedation or uncontrolled anxiety can worsen pulmonary hypertension. Supplemental administration of oxygen is carefully given because most lung transplant

patients depend on their hypoxic drive. Epidural analgesia should be considered in lung transplant patients for postoperative pain control (also see Chapter 40).

Intraoperative Management

In addition to standard monitors, arterial catheters, CVCs, and PACs are usually placed. In some institutions, a PAC with continuous mixed venous O_2 saturation and cardiac output monitoring is used. Endobronchoscopy is necessary during lung transplantation. In addition to assessing the position of the double-lumen endotracheal tube, endobronchoscopy can examine the airway anastomoses for stenosis, bleeding, and obstruction secondary to blood or sputum. TEE is often used during lung transplantation.

Induction of anesthesia needs to balance the risk of aspiration of gastric contents with hypoxia and hemodynamic instability. Positive-pressure ventilation can cause a decreased venous blood return. Patients with severe pulmonary hypertension are at risk of cardiac arrest during induction of anesthesia. Emergent cardiopulmonary bypass is established in this situation. Positive-pressure ventilation can cause further damage to diseased lungs and worsen hypoxia and hypercarbia. Air-trapping and barotrauma should be avoided. Protective ventilation strategies, including small tidal volumes, should be considered.[24]

The most challenging intraoperative issues associated with lung transplant involve ventilation-reperfusion mismatch and PA hypertension. Strategies to treat hypoxemia during lung transplant are similar to those seen in thoracic surgery (also see Chapter 27). At the time of PA clamping, increased PA pressure is often encountered. Methods to reduce PA pressure include intravascular fluid restriction and nonselective and selective pulmonary vasodilators in both intravenous and inhaled forms. Excessive intravascular fluid administration should be avoided because noncardiogenic pulmonary edema is a frequent development in lung transplant patients.

Postoperative Management

Special care for lung transplant patients in the postoperative period is provided to avoid barotrauma, volutrauma, and anastomotic dehiscence during positive-pressure mechanical ventilation.

PANCREAS TRANSPLANTATION

The most common indication for pancreas transplantation is type 1 diabetes. However, more transplants have been performed in patients with type 2 diabetes in recent years.[25] The transplanted pancreas can provide endogenous insulin and restore normoglycemia and the glucagon response. Diabetes mellitus affects cardiovascular, autonomic, nervous, renal, gastrointestinal, and metabolic systems. Preoperative evaluation should focus on functional status of the vital organs. Ischemic heart disease is a primary cause of perioperative death. Diagnosis of coronary artery disease in this patient population is difficult in the presence of neuropathy and silent ischemia. If coronary artery disease is suspected, a preoperative stress test or coronary artery angiogram should be performed. Preoperative evaluation should also include examination of renal function, acid-base status electrolytes, and hemoglobin. Most pancreas transplants are performed simultaneously with kidney transplantation. Compared with pancreas alone or pancreas after kidney transplant, simultaneous pancreas and kidney transplants experience the best graft survival rates.[25]

Pancreas transplantation can be performed under general or regional anesthesia. Invasive monitors should be considered if there is cardiovascular disease. The choice of anesthetic drugs should take into account the possibility of severe postinduction hypotension due to diabetic autonomic nervous system dysfunction. Administration of NMB drugs not dependent on renal excretion for their elimination is preferred if renal function is impaired (also see Chapter 11). Severe intraoperative hyperglycemia should be avoided because it may adversely affect islet function and promote posttransplant infection.

CONCLUSIONS

Patients presenting for organ transplantation have end-stage disease of one or more organs, and many are critically ill. Anesthetic management tailored to the patient's comorbid conditions is vital for successful transplant. Vigilant anesthetic care, both before and after the transplant, can have a profound impact on minimizing these complications and improving posttransplant outcomes. Successful transplantation reverses organ failure and promotes the recovery of organ systems beyond the transplanted organ.

QUESTIONS OF THE DAY

1. How should the risk of cardiovascular disease be evaluated in a patient who requires kidney transplantation?
2. What are the most common indications for liver transplantation in the United States? How is the model for end-stage liver disease (MELD) score used in the allocation of liver grafts?
3. What are the three phases of the liver transplant procedure? What are the manifestations of reperfusion syndrome?
4. A patient develops bradycardia immediately after heart transplantation. What are the unique aspects of managing the patient's hemodynamics in this setting?

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