I. Types of assist devices
   a. Intra-aortic balloon pump (IABP)
      i. Works by counterpulsation out of phase with the cardiac cycle
      ii. Inserted via femoral artery or aortic arch
      iii. Advantage: anticoagulation not required
      iv. Pediatric disadvantages: size limitations, rapid heart rate
      v. Contraindications
         1. PDA
         2. Recent aortic arch surgery/ significant aortic insufficiency
   b. Extracorporeal membrane oxygenation (ECMO)
      i. Full cardiopulmonary support
      ii. Nonpulsatile
      iii. Generally veno-arterial cannulation
      iv. Most commonly used support in infants and children
      v. Can act as bridge-to-bridge or “double bridge” support
      vi. Components
         1. Arteriovenous or venovenous circuit
         2. Roller pump or centrifugal pump
         3. Oxygenator
         4. Heat exchanger
   c. Centrifugal pump ventricular assist device (Biomedicus)
      i. Capable of uni- or biventricular support
      ii. Nonpulsatile
      iii. Simpler design than ECMO circuit
      iv. Oxygenator may be added to circuit
   d. Paracorporeal ventricular assist device (LVAD, RVAD or BiVAD)
      i. Thoratec: minimum BSA approximately 0.7 m²
      ii. Berlin Heart and MEDOS HIA VAD: multiple sizes available but not FDA approved
      i. Continuous flow, no valves
      ii. No compliance chamber
      iii. Only support left heart
      iv. Mobility and home support possible
   f. Total artificial heart: Cardiowest TAH
      i. Advantage: avoids native heart issues such as arrhythmias
      ii. Disadvantage: Removal of native heart
      iii. Need BSA of approximately 1.2 m²
II. Criteria for choosing a mechanical circulatory support device

a. Duration of use
   i. Short term (< 30 days)
      1. IABP
      2. ECMO
      3. Centrifugal pump
   ii. Long term
      1. Pulsatile
      2. Nonpulsatile: Axial
      3. Total artificial heart

b. Degree of support needed: uni or biventricular, pulmonary

c. Size of patient
   i. No limits: ECMO, Biomedicus centrifugal pump
   ii. Size not limited on Berlin EXCOR but not FDA approved

d. Desire for extubation and ambulation

III. Indications/contraindications for mechanical circulatory support

a. Indication: All states of cardiac failure that are either reversible within a variable period of time or that require transplantation
   i. Unloads the heart
   ii. Provides adequate peripheral circulation to support organ function

b. Patient population
   i. Nonsurgical patients: cardiomyopathy, myocarditis, neoplasm, intractable arrhythmias, pulmonary hypertensive crisis
   ii. Postcardiomyotomy patients: failure to wean from CPB, low cardiac output, severe ventricular dysfunction, postoperative arrest
   iii. Patients awaiting transplant
   iv. Preoperative stabilization: TAPVC
   v. Airway issues: TOF/absent pulmonary valve, tracheal stenosis
   vi. Other: hypothermia, near drowning, drug toxicity

c. Contraindications
   i. Severe neurological damage
   ii. Multiorgan failure
   iii. Irreversible septic shock
   iv. Hemorrhage/coagulation disorders
   v. Multiple congenital anomalies
   vi. Extreme prematurity

d. Complications
   i. Bleeding
   ii. Thromboembolism
   iii. Infection
   iv. Hemolysis
   v. Multiorgan failure
IV. ECMO and pediatric heart disease: advantages/disadvantages and outcomes
   a. Advantages of ECMO
      i. Ease and rapidity of implementation
      ii. Peripheral cannulation
      iii. No size limitations
      iv. Biventricular support
      v. Effective oxygenation
      vi. Large neonatal and pediatric experience
   b. Disadvantages of ECMO
      i. Use of blood products
      ii. Need for higher levels of anticoagulation
      iii. Difficulty of left atrial decompression
      iv. Complex circuitry
      v. Limited duration of support
      vi. Less successful in single ventricle patients

V. Ventricular assist devices: advantages/disadvantages and outcomes
   a. Centrifugal pump
      i. RCH experience: 95 patients post cardiac surgery
         1. Weaning probability 0.66
         2. Discharge probability 0.4
      ii. USCF experience: 15 patients post cardiac surgery
         1. Median age 24 days, median weight 3.7 kg
         2. Hospital survival .67
      iii. Advantages: simpler circuit than ECMO, no size limitations, less anticoagulation than ECMO
      iv. Disadvantages: limited duration of use
   b. Thoratec VAD
      i. Disadvantage: smallest child use approximately 17 kg
      ii. Advantage: long term support
         1. 101 children between 7 and 17 years reported worldwide
         2. Survival .68
   c. Berlin Heart EXCOR
      i. Advantage: multiple sizes available; infant support possible
      ii. Disadvantage: not available in the US
      iii. 45 patients supported
         1. Overall survival .49
         2. Lower survival in children < 10 kg and postcardiotomy patients
         3. Rate of neurologic complications .11
   d. MicroMed DeBakey Child VAD
      i. Available under investigation device exemption (IDE)
      ii. Size limitation: greater than 0.7 m² BSA

VI. ECMO vs. VAD: which is best?
   a. Children more frequently require cardiopulmonary support due to hypoxemia, pulmonary hypertension and RV failure
   b. Adults usually have pure left ventricular failure
   c. VAD more completely unloads the LV allowing reverse remodeling
   d. Neurologic complications are greater in children receiving ECMO support
VII. Future trends in mechanical support for children

a. Continued evaluation of axial flow devices via IDE
b. Recent NIH funding for development of pediatric cardiac assist devices

References


   A retrospective study comparing survival rates in children requiring either ECMO or VAD support and examining the impact of various clinical parameters on survival.

   This paper compares ECMO vs. VAD support in pediatric cardiac patients, examines current trends in use of ECMO for rapid resuscitation and fulminant myocarditis, and discusses future devices for pediatric mechanical circulatory support.


   Excellent review article detailing available devices.


   One institution’s review of 12 patients ranging in age from 11 to 20 years who received HeartMate LVADs.


   An examination of long term outcome in patients with cardiac disease who required either ECMO or VAD support.

   Increased rate of survival reported with shunt open during support, using increased pump flows to adequately perfuse the systemic and pulmonary beds.

   This paper describes the use of the MEDOS HIA VAD in six pediatric patients ranging in age from 5 days to 8 years.
Merkle F et al. Pulsatile mechanical cardiac assistance in pediatric patients with the Berlin Heart ventricular assist device. JECT 2003;35:115-20.

Prolonged circulatory support for bridging until cardiac recovery or transplantation in 424 pediatric patients. The advantages of the Berlin Heart VAD over centrifugal pumps and ECMO are described.


A description of the use of the Thoratec VAD to support 58 patients ranging from 17 to 93 kg and from 7 to 17 years of age.


A review of outcome data using the Thoratec VAD, Medos VAD and the Berlin Heart in children in the US and Europe.


This paper reviews the authors’ experience with 11 patients requiring left and/or right ventricular assist devices and discusses the anesthetic considerations involved in care of these patients.


An overview of available support modalities for children.


A retrospective review of survival rates post-cardiac transplant for three groups of patients: pre-transplant outpatients, critically ill patients not requiring VAD support pre-transplant, and patients resuscitated and supported with VADs pre-transplant.


An excellent overview of ECMO, IABPs and various VAD devices with background history and diagrams.


A retrospective review of 34 patients ranging in age from 2 to 258 days who required ventricular support post CPB.