Circulatory Assist Devices

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Summary:

The circulation has to be assisted by mechanical assist devices in cases of refractory heart failure. These devices allow the ventricles to recover by restoring adequate perfusion by augmenting the cardiac output and decreasing the load on the heart. In the last 40 years the technology of these circulatory assist devices has improved and has led to their widespread clinical application. Survival rates have improved and morbidity is on a decline. Several patients have been supported for more than one year. Efforts are on for achieving the ultimate goal of manufacturing a implantable total cardiac substitute which is biologically acceptable and functional for a long period. The concept of dynamic cardiomyoplasty and dynamic aortomyoplasty is new and novel method for supporting chronically failing heart. This article reviews various circulatory assist devices and the concept of cardiomyoplasty along with their historical background, mechanism of action and criteria for patient selection.

Key Words:

Left Ventricular Assist Device, Total Artificial Heart, Cardiomyoplasty[1] Aortomyoplasty, Balloon Counter Pulsation.

In severe cardiac failure the heart shows little or no response to Frank - Starling mechanisms of cardiac contraction. Therefore, the circulation has to be temporarily assisted by mechanical assist devices which decrease cardiac work, restore adequate perfusion and allow the ventricles to recover and function under more physiological conditions.

Historical Background

Initial efforts were centered to the development of devices that would temporarily support circulation during intra cardiac repair. This resulted in the first successful use of cardiopulmonary bypass by Gibbon in 1952[1]. In the next 10 years its clinical application was extended and it was used in acute myocardial infarction with cardiogenic shock by Stukey[2] and in patients of massive pulmonary embolism by Denton Cooley[3]. However, it soon became apparent that in usual clinical settings the mechanical support was needed for longer periods and this technique was not suitable. In 1960's investigators were busy developing methods for isolated ventricular support. In the same period, Dennis introduced the method of isolated left heart support[4] while Debakey implanted a left atrial to aortic bypass pump in patients who could not be successfully weaned from cardiopulmonary bypass[5]. However, a major advancement was made when Clauss and Birtwell introduced the concept of counter pulsation. It called for the withdrawal of arterial blood in systole and rapid reinfusion during diastole, resulting in systolic unloading & diastolic augmentation.

In 70's although intra aortic balloon counter pulsation remained the primary method of circulatory support, various external and internal ven-

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tricular assistance devices came into scene[6,7]. 1980's saw a real revolution in the concept of circulatory assist devices. Pneumatically driven total artificial heart[8], electrical left ventricular assist devices, percutaneous cardiopulmonary bypass[9] ,and haemopump found their way in the clinical arena. Very recently, newer techniques like dynamic cardiomyoplasty, ascending aortomyoplasty, descending aortomyoplasty have been successfully used to assist the failing heart.

Mechanism of Beneficial Effects

Mechanical circulatory assistance reduces cardiac work by unloading the heart and restoring adequate perfusion to the vital organs. This brings about a decrease in myocardial oxygen demand and allows the ventricles to function under more physiological conditions. Adequate perfusion leads to reversal of acidosis, hypoxia, vasoconstriction, hypotension and organ dysfunctions. Often the myocardial recovery takes place in two stages. First is the phase of rapid functional recovery of the cells in marginally ischaemic area. Second is the phase of slower process of hypertrophy of normal and recovering myofibrils.

Criteria for Patient Selection

Candidates of mechanical circulatory assistance can be grouped into three major categories. They may be patients with cardiogenic shock owing to post cardiotomy heart failure or of acute myocardial deterioration with or without acute myocardial infarction. It is also used as a bridge to cardiac transplant, in patients awaiting heart transplantation.

Haemodynamic Criteria for Mechanical Circulatory Support

1. Cardiac Index <1.8 litre/m^2/min.
2. Systolic BP <90 mmHg.
3. Left atrial pressure >20 mmHg.
4. Urine output <10 ml/hr.
5. Systemic vascular resistance >2100 dynes sec cm^{-5}.
6. Metabolic acidosis.

All these parameters should be present despite adequate correction of preload, metabolic disturbances and maximum pharmacological support. Maximum ionotropic support is said to be present when any two or more of the following is used in combination —> 10 mcg/kg/min. or more of dopamine, dobutamine or amrinone or 0.2 mcg/kg/min. or more of epinephrine infusion. Patients with serious systemic and metabolic diseases and malignancies should be excluded.

Types of Circulatory Assistance Devices

They are usually classified on the basis of the time of their intended use into resuscitative and intermediate or long term devices as follows:-

Resuscitative Devices

1. Intra aortic balloon counter pulsation.
2. Extra corporeal membrane oxygenation.
3. Haemopump.

Intermediate to Long Term Devices

1. **Ventricular Assist Devices**

   A. **External Devices**

      (1) Pulsatile Pumps

         a) Pusher plate system.

         b) Pneumatically driven systems.

      (2) Non-Pulsatile Pumps (Centrifugal Pumps).

      (3) Roller Pumps.

   B. **Implantable LV Assist Devices (LVAD)**

      (1) NovaCor LVAD.

      (2) Thermo cardiosystems LVAD.

2. **Total Artificial Heart**

3. **Dynamic Cardiomyoplasty/Aorto myoplasty**

Intra Aortic Balloon Counter Pulsation (IABP)

It is the most commonly used method of circulatory assistance. Except for the improvement in the device and method of insertion, nothing substantial has changed in last twenty years. In it a catheter mounted long narrow balloon is placed into the thoracic aorta via percutaneous route through femoral artery. It is pneumatically driven and is inflated during diastole thereby increasing diastolic blood pressure and coronary perfusion and deflated during systole thereby reducing the afterload of the left ventricle. The inflation or deflation is synchronised with either EKG or arterial pressure waveform. Patients are usually maintained on IABP for short periods and are gradually weaned off. It is useful in situations of cardiogenic shock, medically refractory unstable angina, limitation of infarct size in uncomplicated acute myocardial infarction, haemodynamic instability at the time of PTCA or cardiac surgery, during intractable ventricular tachyarrhythmia and in patients with recent myocardial infarction and advanced heart disease who require general anaesthesia during non-cardiac surgery. The capability of IABP to effectively assist circulation is compromised in patients with cardiac index less than 1.5 L/m^2/min. and in those with rapid and irregular cardiac rhythms. It is contraindicated in presence of aortic regurgitation, PDA, bleeding diasthesis, sepsis and severe diffuse arteriosclerotic disease of femoral artery and aorta.

Femoro-Femoral ECMO (Extra Corporeal Membrane Oxygenation)

It is a resuscitative mechanical circulatory assistance device used in settings of cardio-respiratory arrest[10,11]. Though excellent for rapid resuscitation, it is ineffective for more than 48 hours. Survival rates of 17-22% have been reported by use of this device in clinical trials. Massive bleeding due to anticoagulation is a major complication in the use of Extra Corporeal Membrane oxygenation.

Haemopumps

They consist of small spiral vane rotating at a speed of 17000-25000 rpm. They are implanted into the LV cavity through femoral artery approach. Blood is removed from the left ventricle and is pumped into the aorta. They can also be positioned into the iliac arteries or ascending aorta. Although clinical trials[12] are currently in progress, survival rates of 20-25% have been reported.

External Ventricular Assist Devices

These may be either pulsatile, non-pulsatile (centrifugal pumps) or roller pumps. The pulsatile pumps function as blood sac to which external pressure is applied during ejection to force blood into the arterial tree. These sacs may be compressed externally by either gas or pusher plates. The centrifugal pumps cause non pulsatile rotational acceleration of blood by means of a spinning impeller powered by electric motors. Roller pumps are the same as standard roller pumps used in the dialysis machines. Blood is drained from left atrium and returned to ascending aorta through a single silicone tube that runs through the roller head. They are cheap, more familiar and simple to set up and operate. Flow rates of upto 4 litres per minute can be obtained.

Implantable Left Ventricular Assist Devices

These are particularly important since they are prototype of permanent systems which may provide an alternative to cardiac transplantation. Although several devices are being developed only two of them are currently undergoing clinical trials in post cardiotomy patients and as a bridge to cardiac transplantation[13,14]. These devices are inserted into the left ventricle from which blood is drawn and pumped into the ascending aorta. NOVOCOR LVAD, is electrically driven and has the advantage of excellent patient mobility as electric power cable is the only element traversing the skin. Patients have been maintained on this device for little more than a year. Thermocardiosystem's LVAD is similar to Novocor device except that compressed air is used as a power source. Moreover, it has a textured surface which promotes the development of viable biological linning thereby

reducing the incidence of thrombosis. Patients have been successfully supported on this system for 271 days before successful heart transplantation.

Total Artificial Heart

The project of developing total artificial heart was undertaken by several laboratories in Europe and U.S.A. as early as 1950's. However, the real progress was made when National Heart Lung Blood Institute began a formal programme in 1960.

Two types of artificial hearts have been developed. They are - pneumatically driven pumps and electric motor driven pumps. Of the pneumatically driven pumps, the Jharvik's Pump[15,16] designed at the University of Utah and the heart designed at the Penn State University have received most attention. Both these devices are similar in design and functions except for a little difference in the angulation of the inflow and outflow ports and in the control of their operations. Electrically driven pumps are still in the animal testing phase and have not been used clinically.

The placement of total artificial heart requires the removal of patient's ventricles. Polyurothane cuffs are then sewn to native atria and the arterial prosthesis are anastomosed to pulmonary artery and aorta. The heart is then deaired and anticoagulation is initiated. Because of major complications like thrombosis, haemorrhage, embolism and infections it has not been used widely. Maximum reported survival on Symbion total artificial heart is fortyfive days. However, studies are on way for better and larger acceptability by the patients.

Dynamic Cardiomyoplasty/Aortomyoplasty

These are the most recent surgical procedures to support chronically failing heart. Here latissimus dorsi muscle after proper conditioning, is wrapped around left ventricle and ascending or descending aorta and sequentially paced so that it augments forward ejection of blood.

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