Mechanical support of the heart

Barbora Parizkova
I Gavin Wright
Emma J Birks

Learning objectives

After reading this article, you should be able to:

- summarize the indications for mechanical support
- classify ventricular assist devices into three types
- list the main specific anaesthetic concerns associated with ventricular assist device implantation

Abstract

Mechanical support of the heart can be offered to patients who are refractory to pharmacological treatment, therapy for coronary or valvular disease or resynchronization therapy. Ventricular assist devices enable end-organ perfusion in the setting of heart failure. This can be temporary (as a bridge to recovery or transplantation) or permanent (destination therapy). Devices can be extracorporeal or implanted, and generated flows can be pulsatile or non-pulsatile. Implantation usually requires sternotomy with or without cardiopulmonary bypass, but percutaneous devices exist. Cardiostable anaesthesia with inotropic support is vital. Problems include bleeding versus thrombosis, high pulmonary vascular resistance, right heart failure and late infections. Transoesophageal echocardiography can be used to detect potential right-to-left atrial shunts, aortic regurgitation and cannula malposition, and to monitor filling and right ventricular function after implantation. In the future, total implantability of the devices, including the power source, is likely to occur. Eventually, they are likely to become a widespread alternative to transplantation.

Keywords Bridge to transplantation; destination therapy; heart failure; mechanical support; ventricular assist devices

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Introduction

Heart failure is indicated in approximately 20% of all hospital admissions among people older than 65. It has multiple causes, including ischaemic heart disease, cardiomyopathy, valvular heart disease and congenital heart disease. Cardiac transplantation is the first-line treatment for heart failure in advanced patients with New York Heart Association class IV symptoms, but few donor organs are available. Mechanical support of the heart can be offered to patients who are refractory to pharmacological treatment, therapy for coronary or valvular disease or resynchronization therapy. Stem cell and gene therapy both offer promise for the future.

The earliest forms of mechanical cardiac support were cardiopulmonary bypass, introduced in 1953 and used for cardiopulmonary support during cardiac surgery, and intra-aortic balloon counterpulsation (IABP), introduced in 1962 and used for temporary partial haemodynamic support and to improve coronary perfusion. The first left ventricular assist device (LVAD) was implanted by Cooley in 1969.

Ventricular assist devices (VADs) enable end-organ perfusion in the setting of heart failure. VADs are used as a 'bridge to recovery' to support patients after myocardial infarction and for those with non-ischaemic cardiomyopathy or those who cannot be weaned from cardiopulmonary bypass. VADs are mainly used as a temporary measure to allow patients to survive and improve their overall condition while they wait for heart transplantation (bridge to transplant; BTT). Destination therapy (as an alternative to transplantation) is becoming established in clinical practice and is expected to be of growing importance in the future.

Devices

VADs are available as extracorporeal and implantable types. The available devices can be classified into three types: centrifugal pumps, volume-displacement pumps and axial-flow pumps.

Extracorporeal devices

The most commonly used are centrifugal pumps that produce non-pulsatile flows of up to 8 litres/minute. These are used for temporary left, right or biventricular support either as a bridge to decision in moribund patients, for patients with postcardiotomy heart failure, for temporary right ventricular support, or for post-transplant allograft failure. They can be used with an oxygenator for extracorporeal membrane oxygenation. Heparin is required during use. The Levitronix VAD is an example of a centrifugal pump. Extracorporeal pulsatile pumps include an inflow valve (bioprosthetic or mechanical), which allows unidirectional flow into the device and prevents regurgitation during mechanical systole, and an outflow valve to prevent regurgitation during mechanical relaxation. The BVS 5000 (Abiomed, USA) and the Thoratec biventricular assist device (Thoratec Corp., Pleasanton, CA, USA) (Figure 1) are examples of extracorporeal pulsatile pumps. They require long-term anticoagulation with warfarin with or without aspirin.

Total artificial hearts

Total artificial hearts are generally volume-displacement devices, generating pulsatile flow through the filling and compression of

Barbora Parizkova *MD is an Anaesthetic Specialist Registrar at the Papworth Hospital NHS Foundation Trust, Papworth Everard, Cambridge, UK. Conflicts of interest: none declared.*

I Gavin Wright *MB ChB FCA(SA) is a Consultant Anaesthetist and Intensivist at the Royal Brompton and Harefield NHS Foundation Trust, London, UK. Conflicts of interest: none declared.*

Emma J Birks *MRCP PhD is a Professor of Medicine and Director of Heart Failure, Transplantation and Mechanical Support at the University of Louisville, USA. Conflicts of interest: none declared.*

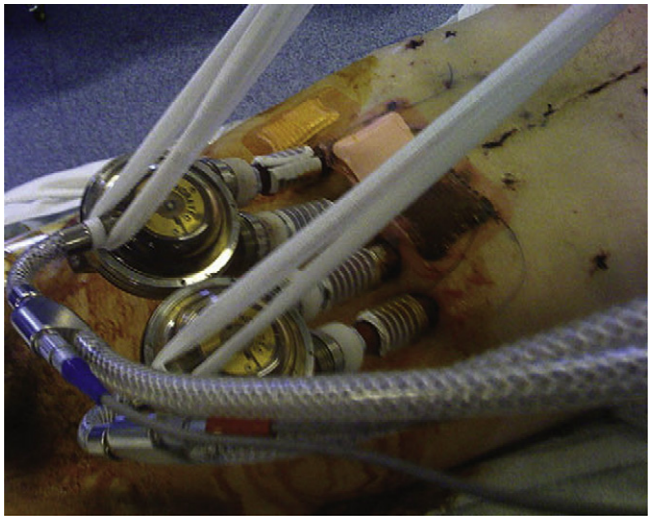

Figure 1 A patient with a Thoratec biventricular assist device (Thoratec Corp., Pleasanton, CA, USA) who underwent intra-abdominal surgery. The device consists of a single-chamber pump with mechanical inflow and outflow valves. Alternating positive and negative air pressure within a flexible sac moves blood through the pump and causes pulsatile flow. A flow rate of 7 litres/minute is possible. The anaesthetist has to consider the effect of surgical positioning (here, lifting of the device with white tapes) on venous return, because an adequate circulating blood volume is an important factor for maintaining device output.

an internal chamber with air. During implantation of such a device, the patient's own left and right ventricles are removed and the device is inserted in the same anatomical location as the heart. Examples of total artificial hearts include the CardioWest device (SynCardia Systems, Tucson, USA) and the AbioCor (Abiomed, Danvers, Massachusetts, USA).

Implantable devices

These are designed for longer term use and are smaller pumps, allowing patients to have better mobility and quality of life. They generally have lower infection rates, although they still require a power source through a percutaneous driveline which can be a source of infection.

The HeartMate XVE (Thoratec) is a pulsatile implantable pump available as a bridge to transplantation, and it is also approved for destination therapy. However, it is believed that this pump will last only 1–2 years before requiring replacement. Concerns about durability along with the high rate of complications have restricted the wide adoption of this therapy for patients with end-stage heart failure. There are two types of continuous-flow pumps: axial and centrifugal. All pumps utilize an impeller to generate flow. The axial pumps include the HeartMate II (Thoratec), the Jarvik 2000 FlowMaker (Jarvik Heart, New York, NY, USA), and the INCOR (Berlin Heart AG, Berlin, Germany). The spinning of the impeller draws blood from the inflow orifice or cannula through the device to the outflow cannula. The HeartMate II is an axial-flow pump providing flows of 3–10 litres/minute at between 8000 and 12,000 rpm. The device measures 4 cm in diameter and 6 cm in length and has a mass of 375 g. The centrifugal pumps include DuraHeart (Terumo Cardiovascular Systems, Ann Arbor, MI, USA), VentrAssist (Ventracor, Chatswood, NSW, Australia, Figure 2), and Heartware (Heartware Inc., Miami, FL, USA). Heartware is

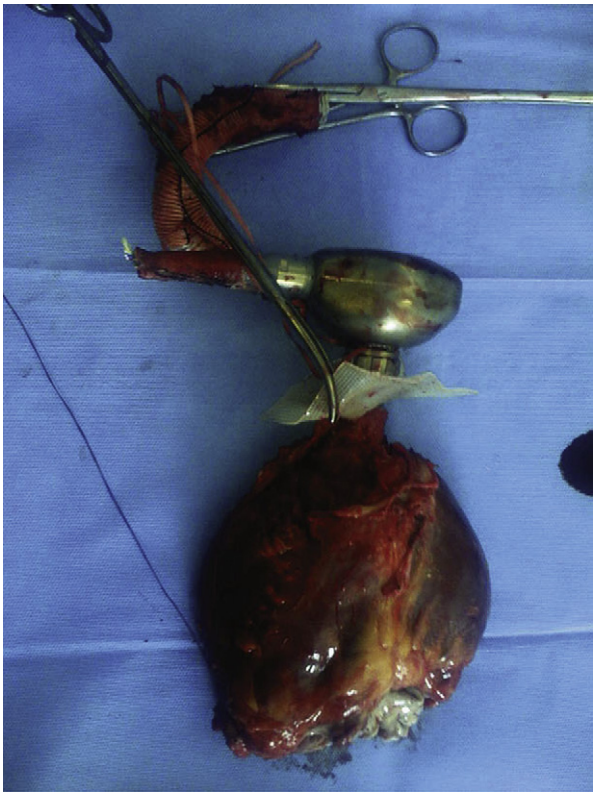

Figure 2 Bridge to transplantation. Explanted heart with a VentrAssist device *in situ* (continuous-flow pump) from a patient who underwent heart transplantation.

a centrifugal pump with only one moving part, the impellar, and no mechanical bearings. The impellar is suspended within the pump housing through a combination of passive magnets and a hydrodynamic thrust bearing. The inflow cannula is integrated with the device itself, which is implanted in the pericardial cavity and provides up to 10 litres/minute flow. Most VADs require cardiac surgery for implantation. New percutaneous devices exist. The smallest and least invasive is the Impella pump (Abiomed). It is inserted in the femoral artery and advanced retrogradely into the left ventricle. It aspirates blood from the left ventricle (LV) and expels it into the ascending aorta using a microaxial-flow pump located on the distal end of a catheter. Another percutaneous VAD is the TandemHeart (CardiacAssist), which is an extracorporeal centrifugal pump whose inflow catheter is placed percutaneously in the left atrium through a trans-septal approach and whose outflow cannula is placed in the femoral artery. Both devices require systemic anticoagulation to prevent device clotting. The Cardiobridge device (GmbH, Germany) is sited percutaneously in the descending aorta, coronary steal being a theoretical risk.

Currently, most of the systems in clinical use are operated in a partial support mode, using a fixed speed mode. The continuous-flow pumps have better survival rates than pulsatile pumps when used as a bridge in patients who are waiting for transplantation. Continuous flow is well tolerated. Pulsatility, by virtue of aortic ejection, returns once the heart recovers some function. Before this, a pulsatile arterial trace can exist as ventricular contraction boosts flow through the VAD.

