Implantable left ventricular assist devices

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Abstract

End-stage heart failure represents a major public health challenge and carries a poor prognosis. After a 30-year gestation period, mechanical assist devices are now poised to make a significant impact in the treatment of heart failure patients. This review gives a general overview of the subject and describes some of the devices currently available in greater detail.

Key words: end-stage heart failure, left ventricular assist devices.

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Introduction

The incidence of congestive heart failure (CHF) continues to increase, with more than one million new patients globally being affected each year. The prevalence is between 1% and 3%. It remains a major public health concern and carries a poor prognosis despite major advances in pharmacological therapy.[1] Orthotopic heart transplantation is the only therapeutic modality that offers a potential 'cure' but it is limited by international donor organ shortages and the failure of many patients to meet standard eligibility criteria.[2,3] Thus mechanical circulatory support (MCS) or ventricular assist devices (VADs) may offer an alternative approach, and currently there are more than 20 technologies at some stage of development.[4] In the clinical setting VADs have been used mainly as a bridge to transplantation although, more recently, the indications have expanded to include patients considered for bridge-to-recovery[6,7] and alternative-to-transplantation ('destination therapy').

VAD technology

The first mechanical circulatory support device was implanted by Michael DeBakey in 1963.[8] Since then several types of blood pumps have been developed and can be divided into two main groups according to the nature of their flow (table 1). The pulsatile pumps produce a physiological pulsatile flow, driven by pneumatic or electric power. Non-pulsatile pumps produce continuous flow in which there is no pulse pressure and include the centrifugal and axial flow pumps. Other distinguishing features relate to design issues of the device such as its implantability (totally implantable versus paracorporeal), power source and the degree of driveline tethering between the patient and external power source.

Table 1. Classification of blood pumps according to the nature of their flow

Pulsatile pumps	
• Pneumatic	Thoratec, Abiomed, Medos
• Electric	HeartMate I, Novacor, Lion Heart
Non-pulsatile pumps	
• Centrifugal	BioMedicus, Terumo, Jostra, HeartMate III
• Axial flow	Hemopump, HeartMate II, MicroMed DeBakey, Jarvik 2000

Current choice of devices

The HeartMate I (previously Thermo Cardiosystems, Inc, Woburn, MA, but now owned by Thoratec Pleasanton, CA) is a pneumatic actuated pusher plate pump that has been in clinical use since 1986. The vented electric version was introduced in 1992. The pump is relatively large and sits either in the peritoneal cavity or

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Figure 1. The HeartMate I. This is an implantable device that provides only LVAD support and has been used in more than 2,300 patients worldwide

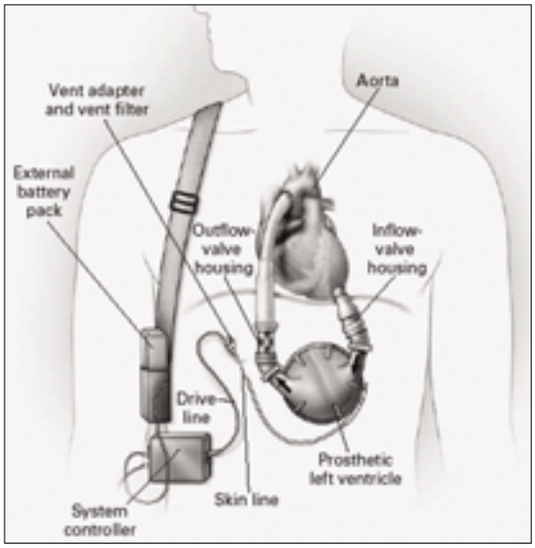

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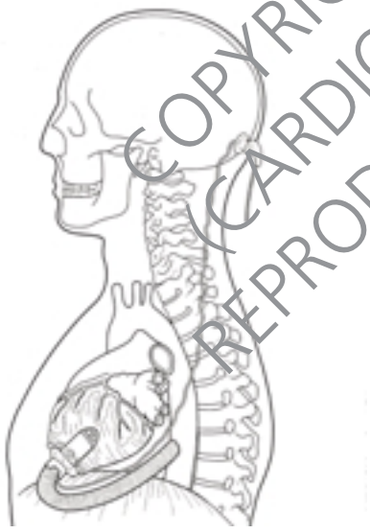
Figure 2. Schematic diagram of the Jarvik 2000. This small axial flow device is showing early promise in the 'destination therapy' of heart failure patients ineligible for transplantation



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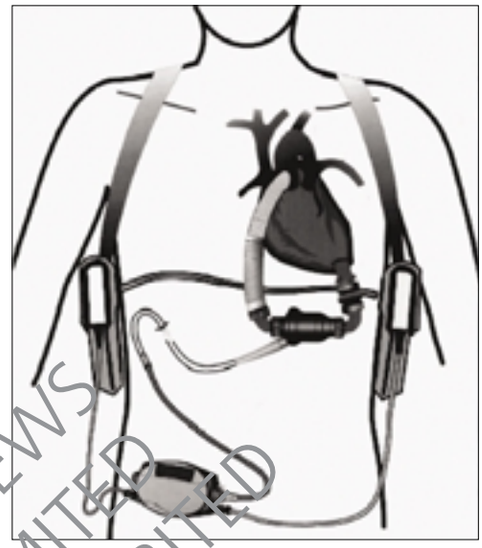
rectus sheath, making it generally inapplicable for use in small patients. Thrombogenicity is low, probably due to the textured inner surface of the pump that promotes fibrin deposition and formation of a 'pseudoendothelium'. The HeartMate I has been implanted in some 2,300 patients worldwide and is generally regarded as the standard device against which all others are compared. The system's wearable components have been miniaturised and include a belt-worn system controller and two re-chargeable batteries to provide about six hours of untethered support (figure 1). Patients fitted with this device are typically able to return to a relatively normal lifestyle and to participate in work and leisure activities.[9]

Figure 3. The Percutaneous HeartMate II. This second generation HeartMate pump has been miniaturised to cater for the smaller patient



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The MicroMed DeBakey is a new axial flow pump developed by collaboration between Baylor College of Medicine and the NASA/Johnson Space Center in the early 1990s. This is an implantable left VAD (LVAD), intended for more than three months support and focusing on bridge-to-transplantation. The first clinical use was in 1998 and since then more than 160 devices have been implanted in patients from both sides of the Atlantic. It represents the first miniaturised device, approximately one-tenth the size of other currently marketed pulsatile VADs. This makes it less invasive and means that it can be used for small adults and children. It can operate up to eight hours on batteries, giving patients untethered mobility and improved quality of life.

The Jarvik 2000, designed by Robert Jarvik, has been evaluated by *in vivo* testing and clinically implanted both at the Texas Heart Institute, Houston, Texas, US and at the Oxford Heart Centre, in the UK.[10] The pump itself is implanted directly in the left ventricle through the apex (i.e. has no inflow cannula) and conducts blood through a 16 mm Dacron graft to the descending thoracic aorta (figure 2). The power driveline is relatively small, is passed superiorly and connects to a titanium pedestal that sits subcutaneously in the left mastoid area. The battery can then be re-charged transcutaneously. The longest UK survivor received his device nearly three years ago.

Figure 4. Schematic diagram of the Thoratec BiVAD device. The Thoratec is a versatile para-corporeal device that can support both the failing left and right ventricle

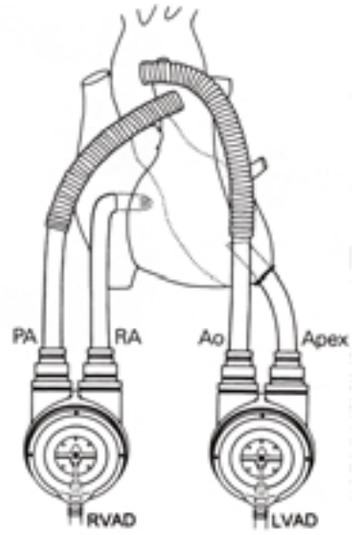

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Figure 5. The AbioCor total artificial heart. The total artificial heart remains in its infancy of clinical application

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The HeartMate II is an axial flow rotary pump utilising blood-immersed mechanical bearings with textured blood-contacting surfaces. The percutaneous configuration (shown in figure 3) is similar in arrangement to the HeartMate I but has a belt-worn system controller and two rechargeable batteries to provide untethered support. The transcutaneous version, however, is totally implantable: it includes a controller, an energy transfer coil and an optional emergency battery pack. A radio communication link maintains contact between the implanted controller and the belt-worn system controller. The pump impeller continuously rotates and generates a forward flow of blood from the ventricle into the aorta. This continuous flow eliminates the need for valves, in contradistinction to the HeartMate I. An algorithm in the HeartMate II controller responds to the changing flow demands of the body by adjusting the motor speed to maintain optimal flow without allowing collapse of the ventricle.

The HeartMate III represents the latest innovation in LVAD technology. It is structured around a centrifugal blood pump that uses a magnetically levitated rotating assembly. It has the potential for higher efficiency overall compared to the HeartMate II and the pump's operating life is not dependent on bearing wear. It is currently undergoing laboratory evaluation. The Terumo device works on a similar principle and has been implanted in a few patients.

The Thoratec device (Thoratec Pleasanton, CA) is a para-corporeal VAD that can be used in the LVAD, right ventricular assist device (RVAD) or bi-ventricular ventricular assist device (BiVAD) configuration (figure 4). Although the pneumatically driven pumps lie outside the body, patients can mobilise with the aid of a battery-powered console and can, in some cases, be managed as out-patients. Full systemic anticoagulation is required to prevent thrombosis on the mechanical valves between the pump and the inflow and outflow cannulae. This is a versatile device particularly suited to patients of smaller body habitus (in whom the HeartMate I is too bulky for intra-abdominal implantation) and those requiring bi-ventricular support for medium- and long-term bridge-to-transplantation.

A number of devices have been developed since the 1960s that fall under the category of cardiac replacement or total artificial heart (TAH). These include the Jarvik 7, CardioWest and more recently, the AbioCor (figure 5). This last received much attention recently when the first successful clinical case was reported from Kentucky, US.[11] The TAH is particularly useful in patients with significant intraventricular thrombus, in whom cannulation for LVAD support would carry a significant risk of systemic embolisation. Similarly, it is useful in those transplant patients who experience frequent and severe episodes of acute rejection, in whom total cardiectomy and TAH bridge-to-transplantation seems appropriate.

Evidence for long-term use of LVAD support for end-stage heart failure – 'destination therapy'

The randomised evaluation of mechanical assistance for the treatment of congestive heart failure (REMATCH) trial[12] randomly assigned 129 patients with end-stage heart failure who were ineligible for cardiac transplantation to receive a Thoratec HeartMate LVAD (n=68) or optimal medical treatment (n=61). The primary end point used was mortality. To be eligible, patients had New York Heart Association (NYHA) class IV heart failure for at least 90 days despite optimal medical therapy, an ejection frac-

Key messages

- End stage heart failure is a growing problem and carries a poor prognosis despite optimal pharmacological therapy
- Orthotopic cardiac transplantation, although it offers a potential 'cure', is limited by donor shortage and patient ineligibility
- VADs can be used as 'bridge to recovery', 'bridge to transplantation' and 'destination therapy'. Large multi-centre randomised trials are needed to evaluate the efficacy of second and third generation devices

tion of < 25% and an exercise peak oxygen uptake of < 12 ml/kg/min.

Kaplan-Meier survival analysis showed a reduction of 48% in the risk of death from any cause in the LVAD group compared to the medically treated group (RR 0.52;9% CI 0.34–0.78; p=0.001). The rates of survival at one year were 52% in the device group and 25% in the medical group (p=0.002), and at two years were 23% and 8% (p=0.09), respectively. The quality of life in the device group was significantly improved at one year as measured by the Minnesota Living With Heart Failure Questionnaire. The incidence of serious adverse events, however, was 2.35 times higher in the LVAD group, with a predominance of infection, bleeding, neurological dysfunction and device failure requiring re-implantation in some cases. Therefore, although REMATCH has been hailed as a landmark study that supports the concept of 'destination therapy' using implantable LVADs, there is much room for improvement. Future multi-centre randomised controlled trials with the second generation devices such as the Jarvik 2000 are needed.

Conclusion

VAD technology has undergone a long gestation period of nearly 30 years, culminating in the birth of a new era of managing end-stage heart failure. We now look forward to the early and late results of clinical studies to determine the true efficacy of mechanical assistance of the heart.

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