# The artificial heart: current concepts

Heart failure is a global problem which predominates in those countries where aggressive medical treatment improves survival after myocardial infarction. In Europe the incidence of heart failure in the over-65s exceeds 100 patients per thousand population, with hospitalization rates of 18 000 per million per year.

The mean age at presentation is 67 years, with 25% of patients older than 75 years. Seventy per cent of patients have a history of myocardial infarction and 15% a history of hypertensive heart disease. Median survival after the onset of heart failure is 2.5 years and hospital readmission rates vary between 29% and 47% within 6 months of discharge. In the CONSENSUS study (1997), patients treated with enalapril spent 15% of their mean 6.5 months follow-up (30 days) in hospital, at a cost exceeding £50 000.

## MANAGEMENT OF CHRONIC HEART FAILURE

The management of advanced chronic heart failure with debilitating symptoms is problematic. For practical purposes, cardiac transplantation is effective but with current donor availability of six hearts per million population, it remains a rare treatment for highly selected patients, under 60 years of age and without significant comorbidity.

Given the labour intensive management of fewer than 300 transplant patients by 10 centres in the UK, it is inconceivable that either conventional or xenotransplantation could expand into the over-65s where the ongoing effects of immunosuppression, rejection and infection would generate an enormous financial burden. For selected patients with ischaemic heart disease and very poor left ventricular function, coronary revascularization already provides outcomes comparable with the intention to treat by transplantation (Louis et al, 1991). Other non-transplant procedures achieve little benefit at high risk.

An ideal therapy for chronic refractory heart failure must be reliable, cost-effective, easy to implement and capable of providing a physiological level of circulatory support. Existing cardiac support devices, such as the pacemaker and implantable defibrillator, are already widely accepted for patients of all ages.

It is only a matter of time before advancing technology produces a realistic mechanical blood pump to substitute for the left ventricle. Within the next 10 years a user-friendly miniaturized left ventricular assist device (LVAD) is destined to become the treatment of choice to relieve symptoms and prolong life in older heart failure patients. Recent experience also suggests that mechanical left ventricular off-loading may reverse left ventricular remodelling in some patients with dilated cardiomyopathy or acute viral myocarditis (Frazier et al, 1996). This raises the possibility of temporary circulatory support in a therapeutic context or as an adjunct to other repair strategies.

## THE TOTAL ARTIFICIAL HEART

The total artificial heart, much publicized in the 1970s and 80s, was conceptually flawed (*Figure 1a*). These cumbersome devices attached to an external pneumatic console were acceptable for bridge to transplantation but were never seriously regarded as a long-term solution. In order to provide quality of life and achieve widespread acceptance, an artificial heart must be more than just a reliable blood pump, it must be forgettable. Whole heart replacement became redundant when it was realized that more than 90% of patients could be sustained with left ventricular support alone. In general, only those with advanced right ventricular pathology or fixed pulmonary hypertension require biventricular support.

Those LVADs currently used for bridge to transplantation have their origins in the total artificial heart era and can be regarded as first generation blood pump technology.

The Novacor (Baxter Heathcare Corp, Oakland, CA) and Thermo-Cardio Systems (Woburn, Mass) LVADs consist of a blood sac in series with the native left ventricle and compressed by a pusher plate mechanism, either electrically or pneumatically driven. Bioprosthetic heart valves dictate

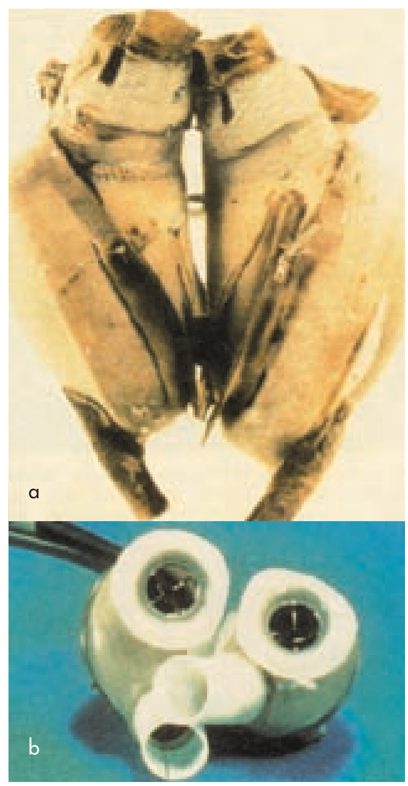


*Figure 1. a. Total artificial heart 30 years ago. b. The thumb-sized intracardiac Jarvik 2000 heart.*

the direction of flow. This mechanism mimics the native left ventricle by providing pulsatile stroke volume with either variable or fixed pump rate. The patient's own left ventricle is completely off-loaded so that the aortic valve does not open.

While large external pneumatic consoles have been replaced by implantable electric systems with a portable controller and power source, the serious problems of LVAD size, noise, driveline infection and thromboembolism persist. Both devices are unsuitably large for most female patients or children. Nevertheless, some bridge to transplant patients have survived with acceptable quality of life for more than 2 years, a record which encouraged us to employ these LVADs for long-term support in patients not eligible for transplantation (Frazier et al, 1995).

The new axial flow impeller pumps are the next generation of artificial hearts. In animal studies these compact, silent, non-pulsatile blood pumps provide up to 8 litres flow per minute without significant haemolysis or thromboembolism (Westaby et al, 1998). The thumb-sized Jarvik 2000 Heart (Jarvik Heart Inc, NY) fits within the apex of the failing left ventricle and pumps blood to the descending thoracic aorta (*Figure 1b*). The impeller, supported by blood immersed micro-ceramic bearings, revolves at up to 18 000 rpm, accelerating blood so rapidly through a narrow channel that the cellular components remain undamaged. The controller and batteries are the size of a portable telephone and fit easily onto a normal belt.

While transcutaneous power induction is under development, we have devised an infection-resistant skull-mounted percutaneous pedestal for the first human implants later this year (Jarvik et al, 1998). A still smaller version providing 3 litres flow is under development for infants and small children.

The extra-cardiac NASA De Bakey (Micromed Inc, Texas) axial flow pump has already been tested for bridge to transplantation in humans with mixed results. Other ingenious blood pumps with magnetically suspended rotors (without bearings) are under development in Japan where only three cardiac transplants have ever been performed.

This new generation of implantable miniature artificial hearts greatly increases the future scope of circulatory support, although mechanical reliability and freedom from complications remains to be established. We must also define the effects of chronic non-pulsatile blood flow, although the native heart does transmit a pulse through the impeller pump.

Most exciting is the potential for myocyte recovery at molecular level if a safe and user friendly LVAD can be employed to rest the left ventricle. At cellular level chronic left ventricular offloading has been shown to reverse myocyte hypertrophy and myocytolysis, arrest apoptosis, and normalize calcium handling by the sarcoplasmic reticulum (Frazier et al, 1996). These changes towards recovery suggest that far more effort should be made to conserve the patient's own heart by earlier intervention rather than supervising decline into irreversibility and multi-organ failure. Potential adjuncts to recovery during LVAD support include new drugs, gene therapy to inhibit apoptosis, transfer of cultured myocytes and neoangiogenesis.

## COST IMPLICATIONS

It is anticipated that the cost of an LVAD will equate with a 3-week hospital admission for acute medical treatment. The LVAD will replace some drug therapy and require only a maintenance dose of warfarin. In 1991 the Technology Assessment Report from the Institute of Medicine (USA) predicted an annual need for chronic mechanical circulatory support in 25 000–60 000 patients by the year 2000. Health-care systems in Germany and France already provide LVADs.

In Britain, both our clinical LVAD use and the Jarvik 2000 research programme have been privately funded. Nevertheless, heart failure surgery will take a giant step with the use of miniaturized artificial hearts in those not eligible for transplantation. **HM**

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## KEY POINTS

- Refractory heart failure is an ever-increasing problem in the over 60s. Neither cardiac transplantation nor conventional surgical techniques can address this population.
- It is only a matter of time before advancing technology provides a blood pump to substitute for the left ventricle.
- Total mechanical heart replacement on a wide scale is conceptually flawed. More than 90% of end stage patients can be sustained by left ventricular support alone.
- Current 'pusher plate' blood pumps have their origin in the total artificial heart era. They are effective for short-term bridge to transplantation in male patients but have a substantial complication rate.
- The new miniaturized axial flow impeller pumps have the potential for widespread use in non-transplant eligible patients in the near future.
- Native heart repair is preferable to replacement. Emerging therapy such as myocyte transfer, gene therapy to inhibit apoptosis and neoangiogenesis may be useful adjuncts to mechanical left ventricular offloading in the future.