THE MICROMED DEBAKEY VAD®: A BRIDGE TO THE FUTURE

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INTRODUCTION

Ventricular Assist Device (VAD) therapy has emerged as a promising new option for the treatment of end-stage heart failure. As a bridge to heart transplantation, pulsatile VAD implantation has been performed over 3,000 times worldwide with a success rate of 50-70%.1,2 In the recent landmark REMATCH (Randomized Evaluation of Mechanical Assistance for the Treatment of Congestive Heart Failure) trial, end-stage heart failure patients, who received VAD but were ineligible for transplantation, were found to have a dramatic survival advantage over patients treated with optimal medical management (OMM).3 On the basis of these results, VAD implantation is now indicated for destination therapy that may impact the care of thousands of patients. Despite the survival advantages associated with mechanical support, these patients are at risk for device-specific complications. The first generation pulsatile Left Ventricular Assist Devices (LVADs) were large, noisy, prone to failure and infection, and expensive (approximately $70,000 per device).1 Recognizing these limitations, researchers began searching for alternative pump designs and axial flow impeller pumps emerged as the second generation of mechanical VAD. This article describes the development by Dr. George Noon, Dr. Michael E. DeBakey, and NASA engineers of the first axial flow pump for tong-term cardiac support.

DEVELOPMENT OF THE AXIAL FLOW DESIGN

In 1984, a NASA-Johnson Space Center (JSC) engineer, David Saucier, underwent cardiac transplantation at The Methodist Hospital in Houston, TX. In 1988, we contacted him to set up a meeting with engineers at NASA who were working with axial flow pumps. Saucier expressed an interest in the ongoing artificial heart research at the Baylor College of Medicine and a collaboration was formed in which NASA spacecraft technology was applied toward the development of an improved VAD. This combined effort resulted in the development of a clinical axial flow pump that differed from existing pulsatile devices in its small size (86-mm long, 25-mm wide, and only 95 g), simplicity of design {only one moving part), and continuous flow characteristics (Figure 1).4 The pump consisted of a titanium inflow cannula, a housing unit containing the impeller and motor, and a Vascutec gelweave vascular graft chat served as an outflow graft for anastamosis with the ascending aorta.

During the development of che pump, initial in vitro studies revealed problems related to hemolysis.5 On the basis of computational fluid dynamic analysis, a flow inducer was added to the from of the pump impeller in order to eliminate high negative pressure areas at the leading edge.[6] Polycarbonate replaced polyether polyurethane in construction of the pumps, after in vitro testing demonstrated thrombus formation on the flow straightener and

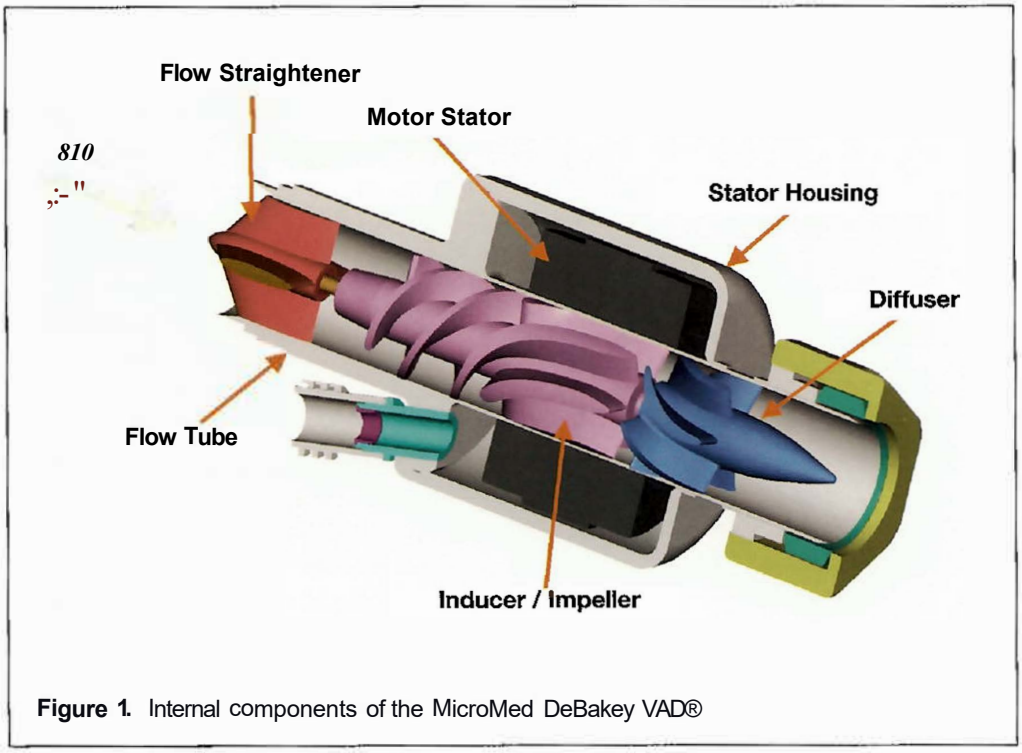

Figure 1. Internal components of the MicroMed DeBakey VAD®

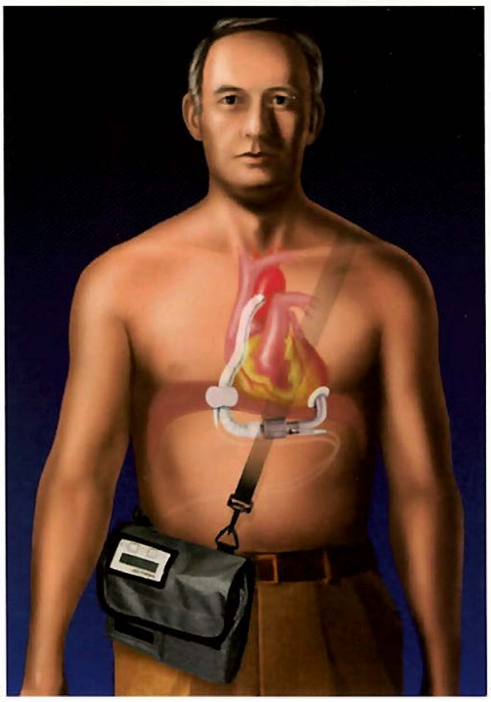

Figure 2. External components of the MicroMed DeBakey VAD®

impeller of developmental models and a computer numerically controlled (CNC) fabrication process was adapted.6 Taken together, these changes produced an index ofhemolysis of 0.0029 +/- 0.0009 g/100 L, well within accepted limits.6

Following successful completion of in vitro testing, the MicroMed DeBakey VAD® was implanted in a paracorporeal position in eight animals. Although the initial ex vivo testing revealed problems with thrombus formation, minor design optimization and heparinizarion alleviated these problems.7,8 The titanium VAD was then evaluated in 19 calves, demonstrating the safety and performance of the device for up to 145 days.9 Thrombus formation, hemolysis and infection were minimal in these studies, and preparations were made for bringing this technology to clinical application.

The final pump design implemented for clinical use was capable of flows of 10 L/min against 100 mm Hg pressure with a speed of 12,500 rpm. A Clinical Data Acquisition System (CDAS) was used to monitor flow curves (via a flow probe positioned over the outflow graft), speed, current and power. An external battery pack was incorporated into the controller module to permit mobility and hospital discharge (Figure 2).

CLINICAL EXPERIENCE WITH THE DEBAKEY VAD

In November of 1998, the DeBakey VAD was clinically implanted for the first time in Europe.10 The surgical procedure for implantation was similar to the one used for first-generation devices, with median sternotomy and initiation of cardiopulmonary bypass (CPB). An extrapericardial, subdiaphragmatic pocket was formed below the rectus muscle on the left side for positioning of the device. An apical fixation ring was sewn to the apex of the left ventricle, followed by insertion of the inflow cannula. The power and flow probe cables were externalized using a trocar via the right lower quadrant of the abdomen, and the outflow graft was anasramosed to the ascending aorta. Following deairing, pump flows were initiated at 7,500 rpm and adjusted for adequate pump index.11• 12

The significance of these first clinical implants cannot be overstated, as this represented the first rime that the human circulation had been supported long term by continuous flow (previous animal studies had suggested the feasibility of chis strategy).13,14 Interestingly, as clinical experience with the device progressed, clinicians began to observe near-physiologic pulsarile blood flow (as measured through Transcranial Doppler studies) in the setting of axial flow supporr.15 Pulsatile flow was attributed to the contractions and pressure changes of the unloaded left **ventricle** and partially recovered right ventricle. The aortic valve often remained closed throughout the cardiac cycle early after implantation.15 However, with some ventricular recovery it would begin to open.

To date, over 240 patients have been supported with the DeBakey VAD as a bridge to transplant, representing the greatest clinical experience for any axial flow pump. Device-related adverse events parallel those associated with first-generation pumps, with linearized rares (events/patient-year) of 2.03 for reoperation due to bleeding, 0.61 for hemolysis, 0.16 for device infection, 0.61 for thromboembolic event, 0.61 for pump thrombus, and 0.13 for pump failure (Table I).1 With a mean support time of 75±81 days, 45% of patients died on support while 55% in the European trial were successfully transplanted.1 The combined FDA feasibility trial had a bridge to transplant success of 67%. These initial findings demonstrate the safety and effectiveness of axial flow as an alternative to pulsarile support.

FUTURE DIRECTIONS

After establishing the success of the device as a bridge to transplantation, MicroMed Technology, Inc. obtained approval from the Food and Drug Administration (FDA) for use of the VAD in a destination therapy clinical trial. The "DELTA" (Destination Evaluation Long-Term Assist) trial will randomize 360 patients in a 2: 1 ratio for i_{mp} lantation of either a MicroMed DeBakey VAD or a Thoratec HearcMare XVE® device. An interim review will be performed following the first 152 implants. This trial represents a significant milestone in the development of a mechanical cure for heart failure in that it may open the door for rotary blood pumps as permanent therapy.

In addition to its potential role in destination therapy, a modification of the DeBakey VAD shows promise as a bridge to transplant in the pediatric population. Since the first successful use of a DeBakey VAD as a bridge to transplantation in a pediatric patient in 1990, mechanical circulatory support has gained increasing popularity in Europe for the treatment of children.16 However, the low Body Surface Area (BSA) associated with this population represents an obvious limitation of implanted pulsatile VADs. For this reason, use of a miniaturized axial flow pump in this subset of patients may be an attractive new application for this technology. After humanitarian device exemption was obtained from the FDA for use of the DeBakey VAD, in children aged 5 to 16 awaiting heart transplantation, this device was implanted successfully in a 6-year-old girl with severe cardiomyopathy. This early experience raises hopes of using axial flow technology to improve outcomes in pediatric heart failure patients.

Nearly two decades after the concept of using an axial flow pump to support the human circulation was first visualized, the DeBakey VAD shows great promise as a treatment for end-stage heart failure. By departing from the traditional mentali$_{t\,y}$ chat pulsatility was an essential requirement of a mechanical assist device, this pump represents an i$_{m\,p}$ ortant bridge to the future ofLVAD technology as a treatment for heart failure.

ADVERSE EVENT	INCIDENCE	RATE/PT-YEAR
Reoperation for bleeding	32.0% (48/150)	2.03
Hemolysis*	12.0% (18/150)	0.61
Device infection	3.3% (5/150)	0.16
Thromboembolict	10.7% (16/150)	0.61
Pump thrombus	11.3% (17/150)	0.61
Mechanical failure	2.7% (4/150)	0.13

• defined as plasma free hemoglobin >40 mg/dl.
t composiste of embolic stroke, transiet ischemic attack, and peripheral embolism.

Table 1. Incidence and Linearized Rate of Adverse Events Following MicroMed DeBakey VAD® Placement.1

REFERENCES

1. *Goldstein DJ Worldwide experience with the .Micro.Med DeBak$_{e\,y}$ Ventricular Assist Device as a bridge to transplantation. Circulation. 2003;108 Suppl l:Il2.""2-II277.*
2. *DeBak$_{e\,y}$ ME A miniature implantabk: axial flow ventricular assist tkvice. Ann Thorac Surg. 1999;68:6r-64o.*
3. *Rose EA, Gelijns AC, .Moskowitz A] et al Long-tenn mechanical left ventricular assistance far end-stage heart failure. N Engl] Med 2001;345:1435-1443.*
4. *DeBak$_{e\,y}$ ME A miniature implantabk: axial jlou• ventricular assist device. Ann Thorac Surg. 1999;68:637-640.*
5. *Damm G, .Mizuguchi K, Bozeman R et al. In vitro perfonnance of the Baylarl NASA axial flow pump. Artif O$_{r\,g}$ans. 1993:l 7.·609-613.*
6. *Mizu$_{g\,u}$chi K, Damm G, Benkowsky R et aL Development of an axial flow ventricular assist de1!ice: in vitro and in vivo emluation. Artif Organs. 1995;19:653-659.*
7. *Kawahito K, Damm G, Benkou>ski R et al Ex l'ii•o phase 1 e„a/uation of the DeBak$_{e\,y}$/NASA axial flow ventricular assist device. Artif O$_{r\,g}$ans. 1996;20:4?-52.*
8. *Kawahito K, Benkou>ski R, Otsubo S et al Ex viw e„afuation of the NASAi DeBak$_{e\,y}$ axial flow ventricular assist dei,ice. &rults of a 2 week screeni$_{n\,g}$ test. ASAJO J 1996;42:M 54-/11J"".*
9. *Fosrum n r; Morley D, Benkou,ski R et al Chronic run·iml of calves imphnted with the DeBak$_{e\,y}$ ventricular assist dei-ice. ArtifOrgans. 1999;23:802-806.*
10. *Wteselthakr Gl'J, Schima H, Hiesmayr M et al Firrt clinical experience with the DeBak$_{e\,y}$ VAD continuous-axial-Jlaw pump far bridge to transplantation. Circuhtion. 2000;101:356-359.*
11. *Noon GP, Morley D, I1win S et al. Dez,elopment and clinical applic,ition of the MicmMed DeBak$_{e\,y}$ i w. Curr Opin CardioL 2000;15:166-171.*
12. *Noon GP, Morley DL, Irwin S et al. Clinical experience with the Micro.Med DeBak$_{e\,y}$ ventricular assist dei>ice. Ann ThoracSurg. 2001; 1.-S133-Sl38.*
13. *Johnston GG, Hammill F. Marzec U et al Prolonged pulseless pnfo.sion in tmanesthetized calves. Arch Surg 1r6;111,1225-1230.*
14. *Golding LR Murakami G, Hara.raki H et al. Chronic no11puls,1tik blbod flom Thms Am Soc ArtifIntern Organs. 1982;28:81-85.*
15. *Potapov £\.; Loebe M, Nasseri BA et al. Pulsatik: flow in patients with a novel nonpulsatik: impbnt,tble ventricular assist device. Circulation. 2000;102: III183-III187.*
16. *Sti!Jer B, Hetzer R. Weng Yet al He,m transplantation in children after mechanical circulatory support with pulsatile pneitmatic assist device. J Heart Lung Transplant. 2003;22:1201-I208.*