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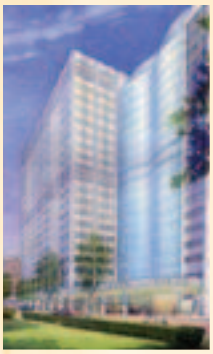

Inside This Issue

Evolving Strategies in the Management of Children With Hypoplastic Left Heart Syndrome

Harold M. Burkhart, MD

Hypoplastic left heart syndrome (HLHS) is characterized by underdevelopment of the structures on the left side of the heart. Infants typically have aortic valve atresia or stenosis, mitral valve atresia or stenosis, a diminutive ascending aorta, and a tiny left ventricle (Figure 1). "Twenty years ago, HLHS carried a fatal prognosis," according to Harold M. Burkhart, MD, a cardiovascular surgeon at Mayo Clinic Rochester. "However, development of the Norwood procedure has dramatically improved the prognosis for these children."

The Norwood operation consists of reconstructing the ascending aorta and arch using the pulmonary valve as the cardiac outlet, constructing a shunt for pulmonary blood flow, and performing an atrial septectomy to allow for unobstructed pulmonary venous drainage to the right ventricle. The Norwood procedure is the first of 3 operative stages leading to successful palliation of HLHS and is usually performed in the first week of an infant's life. The second stage is construction of a bidirectional cavopulmonary shunt (Glenn procedure); the third stage involves a total cavopulmonary shunt (Fontan procedure). Recent modifications to the Norwood procedure along with improved critical care support have resulted in excellent survival rates for these patients or children.

A major recent modification to the Norwood procedure involves the pulmonary blood flow supply. Traditionally, a polytetrafluoroethylene (PTFE) tube from the innominate or subclavian artery to the right pulmonary artery has been used. One of the disadvantages of this type of shunt is that it can be difficult to maintain the delicate balance between pulmonary and systemic blood flow. A decrease in pulmonary resistance can lead to increased pulmonary blood flow, decreased systemic flow, and even coronary artery steal, resulting in cardiac arrest. This potential instability has been blamed for early postoperative deaths as well as interstage mortality (up to 15%). The right ventricle–to–pulmonary artery (RV-PA) PTFE conduit has recently gained support as an alternative pulmonary artery blood flow supply. In this modification, the conduit is sutured to the epicardium of the infundibulum of the right ventricle and then distally to the main pulmonary artery stump (Figure 2). "The RV-PA conduit has the advantage of not being susceptible to pulmonary diastolic runoff and coronary artery steal," says Dr Burkhart. "This has led to much more stable postoperative periods as well as improved survival."

Another evolving area is management of cerebral perfusion during aortic arch reconstruction. Classically, the arch reconstruction has been performed during a period of deep hypothermic circulatory arrest (DHCA). Con-

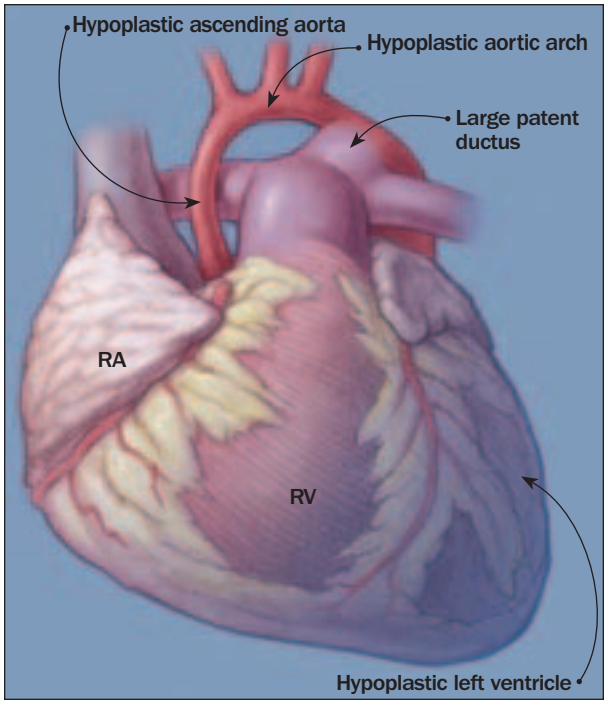

Figure 1. Hypoplastic left heart syndrome. RA, right atrium; RV, right ventricle.

cern for long-term neurologic sequelae such as decreased motor and cognitive function has stimulated an interest in reducing or eliminating DHCA. One technique used at Mayo Clinic Rochester is suturing a PTFE shunt to the innominate artery and using it for the arterial cannulation site. This allows for continuous cerebral perfusion during the aortic reconstruction. Another added benefit is the organ perfusion that is maintained via collaterals when only perfusing the innominate artery. How continuous cerebral perfusion affects the long-term neurologic sequelae is the subject of ongoing investigation.

Aortic arch reconstruction techniques that decrease the incidence of postoperative aortic arch obstruction (AAO) have recently garnered attention. AAO rates of up to 36% have been reported in the literature. AAO is poorly tolerated, with the increase in afterload on the single ventricle leading to atrioventricular regurgitation and worsening ventricular function. Surgical techniques that involve complete mobilization of the arch and head vessels as well as aggressive resection of the coarctation and ductal tissue should be used to reduce the incidence of postoperative AAO.

Advances in critical care and postoperative management have been important in improving outcomes in the Norwood procedure. Ventilator management, availability of newer vasoactive drugs, and the use of mixed venous saturation have all aided in the management of these critically ill infants. Having mechanical support in the form of extracorporeal membrane oxygenation available for patients with poor ventricular function is mandatory. Most important is having a specialized multidisciplinary team available around-the-clock. In addition to the surgical team (surgeons, physician assistants, and residents), the multidisciplinary team involves anesthesiologists/intensivists, pediatric cardiologists, specialized nurses, pharmacists, respiratory therapists, nutritionists, as well as specialists in infectious disease, nephrology, and endocrinology. This team approach allows for thorough postoperative care and is crucial to excellent outcomes.

The Norwood operation is offered to the majority of patients with HLHS. Cardiac transplantation is reserved for patients deemed unsuitable for the Norwood procedure. Occasionally an infant presents with anatomy not suitable for the staged palliation. The presence of severe atrioventricular valve regurgitation or severely depressed ventricular function usually precludes the Norwood operation. Serious consideration is then given to cardiac transplantation. Once the patient is on the transplant list, the biggest obstacle is finding an appropriate match in a very small donor pool. When a match is found, the heart is transplanted along with the donor aorta for arch reconstruction (Figure 3).

"Advances in surgical techniques, including the RV-PA conduit, the avoidance of DHCA, aggressive aortic arch reconstruction, and enhanced critical care with a highly specialized multidisciplinary team, all play a role in achieving improved outcomes for these critically ill infants," says Dr Burkhart.

Cardiovascular Surgery

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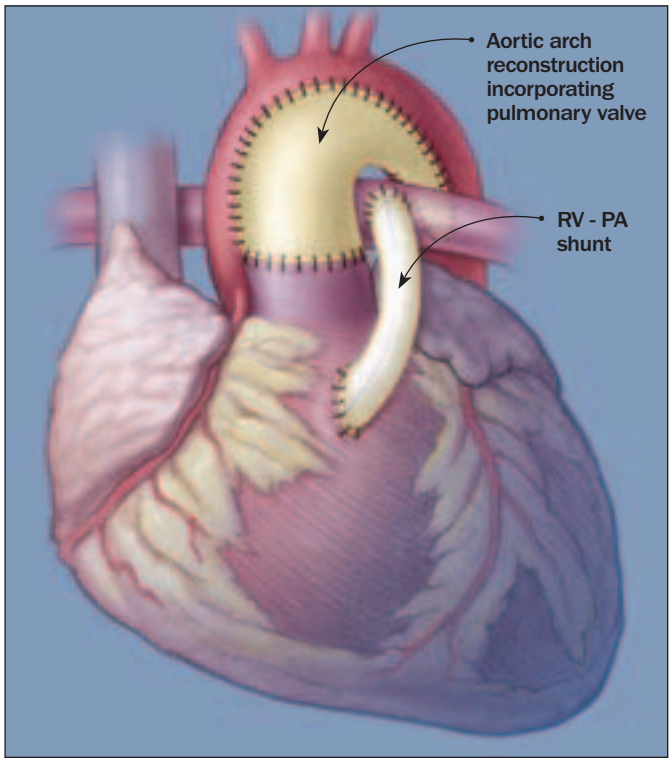

Figure 2. Norwood procedure with RV-PA conduit.

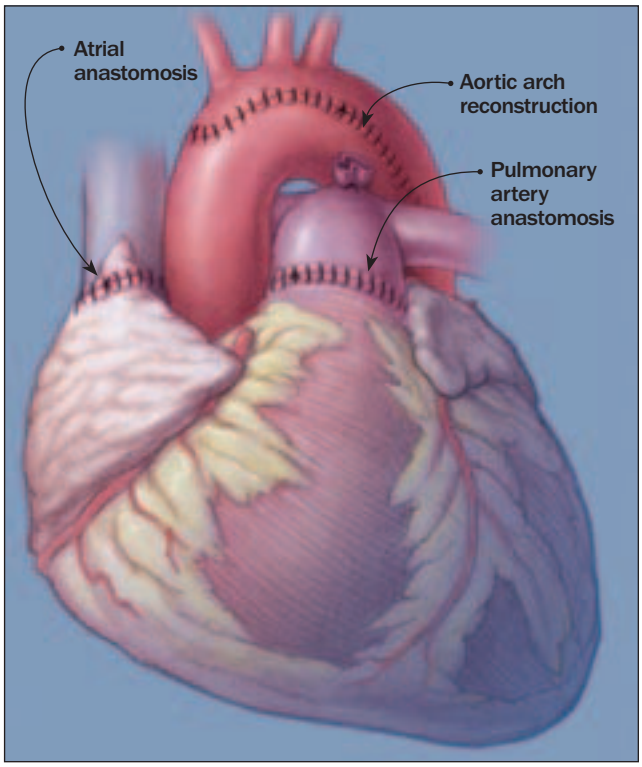

Figure 3. Cardiac transplant in hypoplastic left heart syndrome.

Surgical Treatment of Degenerative Mitral Valve Disease Repair Superior to Replacement

Rakesh M. Suri, MD, DPhil

The management of mitral valve regurgitation (MR) due to degenerative valve disease has evolved greatly during the past 2 decades. During this time, there has been a change in the pathology and consequently the pathophysiology of patients referred for operative treatment. Most patients currently presenting for mitral valve surgery in developed nations have degenerative valve disease consequent to the decline in the frequency of postinflammatory valvulopathy.

Two factors have been influential in broadening the indications for the performance of mitral valve repair: 1) patients are identified earlier and followed more regularly to prevent the deleterious consequences of chronic persistent MR on left ventricular (LV) size and function, and 2) the long-term durability of primary and reoperative valve repair has been clearly established.

Cardiovascular Surgery

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Indications for Surgery

"Detailed longitudinal studies and improved techniques of 2-dimensional and Doppler echocardiography have allowed the identification of evidence-based 'trigger points' at which to recommend mitral valve surgery in those with severe MR," says Rakesh M. Suri, MD, PDhil, a cardiovascular surgeon at Mayo Clinic Rochester. Accurate echocardiographic delineation of both the anatomic cause and the severity of MR has allowed the stratification of patients and the selection of an optimal treatment strategy based on well-defined outcomes. These have been reflected in the revised 2006 American College of Cardiology/American Heart Association Guidelines for the Management of Patients With Valvular Heart Disease (http://content.onlinejacc.org/cgi/reprint/48/3/e1).

Current class I indications for mitral valve surgery in patients with chronic severe MR include

- symptomatic patients without severe LV dysfunction (severe LV dysfunction defined as ejection fraction [EF] <30% and/or LV end-systolic dimension [LVESD] >55 mm) and
- asymptomatic patients having evidence of mild to moderate LV dysfunction (EF 30%-60%) and/or LVESD >40 mm.

Moreover, mitral repair (versus mitral replacement) is recommended in this population whenever possible.

Class IIA indications for mitral valve surgery (preferably repair) in degenerative mitral disease include the presence of chronic severe MR in asymptomatic patients with a normal EF (>60%) if patients

- are sent to a center where the likelihood of a successful mitral repair is greater than 90%,
- have new-onset atrial fibrillation, or
- have documented pulmonary hypertension.

Finally, those with moderate to severe symptoms and severe LV dysfunction along with an anatomic abnormality of the mitral apparatus amenable to valvuloplasty should also undergo repair.

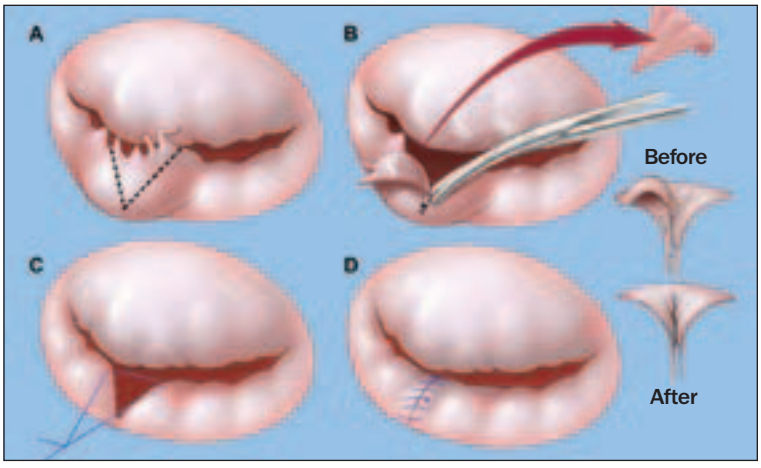

Figure 1. Triangular resection of an unsupported middle scallop of the posterior mitral leaflet (A, B) followed by suture reconstruction (C, D). This eliminates the prolapsing segment and restores normal leaflet coaptation.

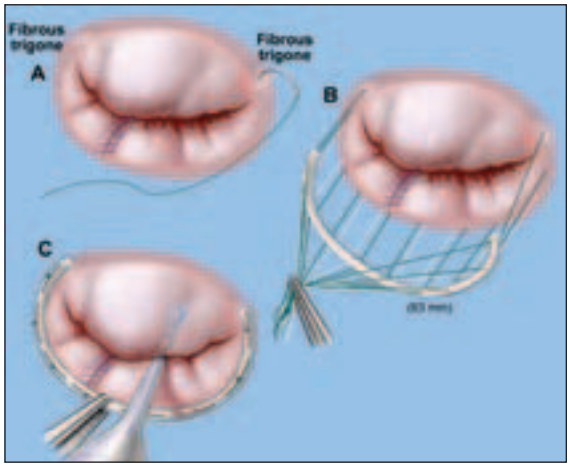

Figure 2. Placement of a 63-mm posterior annuloplasty band anchored in right and left fibrous trigones of the cardiac fibrous skeleton after posterior leaflet repair (A) and anterior leaflet repair (B). Saline testing is done after repair (C).

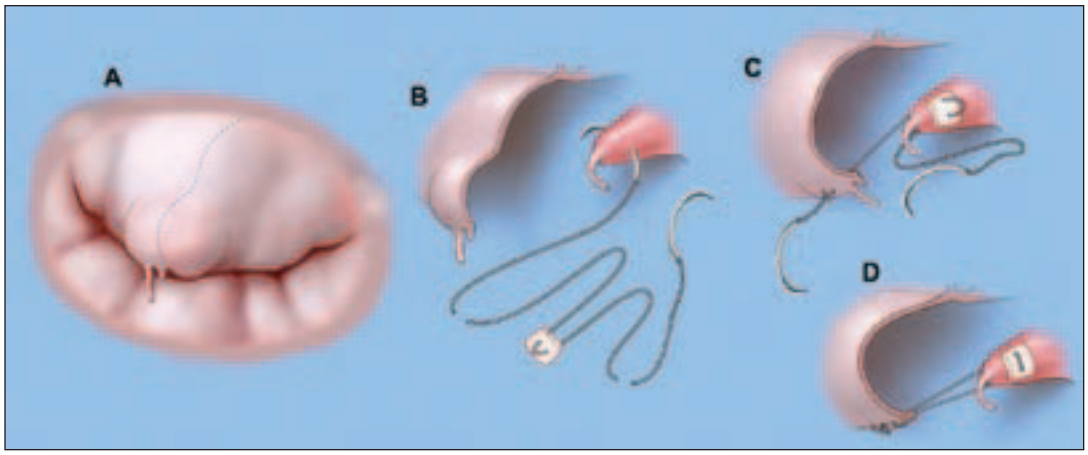

Figure 3. Repair of anterior leaflet prolapse (A). Insertion of artificial Gore-Tex neochordae based on adjacent papillary muscle(s) (B,C,D).

Surgical Methods

The availability of reproducible valve repair techniques as an alternative to prosthetic replacement has dramatically influenced the indications for surgical intervention. With successful valve repair, patients who maintain sinus rhythm resume full activities without need for long-term anticoagulation. "In addition to diminished morbidity, valve repair improves patient survival compared with prosthetic replacement," says Dr Suri. The 409 patients who underwent surgical correction of MR in the 1980s at Mayo Clinic Rochester have been reviewed, and after valve repair, overall survival at 10 years was 68%±6% versus 52%±4% for patients having valve replacement (*P*=.0004). More importantly, multivariate analysis demonstrated an independent positive effect of valve repair on overall survival (hazard ratio [HR], 0.39; *P*=.00001), operative mortality (odds ratio, 0.27; *P*=.026), late survival (HR, 0.44; *P*=.001), and postoperative EF (*P*=.001).

The acute elimination of volume overload characteristic of chronic severe MR results in a decline in postoperative EF. A recent Mayo Clinic Rochester study examined the early change in EF after mitral valve repair and replacement for degenerative leaflet prolapse. Higher postoperative EF at the time of dismissal from the hospital was independently associated with several preoperative variables: greater EF, the absence of atrial fibrillation, better New York Heart Association functional class, smaller LV end-diastolic and end-systolic dimensions, and smaller left atrial size.

The influence of operative strategy on long-term normalization of LV function has been debated. Research at Mayo Clinic Rochester has elucidated factors independently associated with an improved likelihood of long-term recovery of normal EF after surgical correction of MR. These included mitral repair (vs replacement), freedom from preoperative myocardial infarction, operation in the 1990s (vs earlier decades), greater preoperative EF, and smaller LV dimensions. Patients had a higher likelihood of a follow-up EF greater than 60% with a preoperative EF greater than 65% or LVESD less than 36 mm. These factors predicted a higher EF after repair, but not after replacement. Furthermore, those discharged from the hospital with moderate to severe LV dysfunction (EF <50%) were much less likely to regain normal ventricular function during long-term follow-up. Patients who undergo surgical correction of severe MR earlier appear to have a greater likelihood of normalization of LV size/function and survival.

There are likely several mechanisms whereby overall survival is improved with mitral valve repair compared with replacement. Operative mortality is lower with repair due to elimination of device-related complications such as ventricular rupture, thrombus formation, and mechanical malfunction. With valve repair, the chordal apparatus is preserved; studies in patients having valve replacement show that the preservation of mitral valve attachments preserves ventricular geometry and systolic function. Additionally, valve repair has a much lower incidence of late complications than does prosthetic replacement.

The survival advantage of repair over replacement also extends to patients who undergo reoperation for late failure of initial repair. "In our experience with re-repair of the mitral valve, patients have had greatly improved long-term survival along with more complete normalization of LV size and function compared with those having replacement at reoperation," says Dr Suri. Valve repair improves postoperative outcome in patients with primary or recurrent MR and should be the preferred mode of surgical correction. The low operative mortality is an incentive for early surgery before ventricular dysfunction occurs.

Improvements in operative techniques have led to predictable and durable results after mitral valve repair. In the current practice at Mayo Clinic, between 90% and 95% of patients with pure MR due to degenerative disease undergo valvuloplasty rather than prosthetic replacement. The mitral repair procedure is based on the premise that a small triangular resection to eliminate only the redundant prolapsing leaflet edge (caused by either chordal prolapse or elongation) from the coaptation margin is sufficient, expedient, and durable (Figure 1). All repairs are protected with a 63-mm posterior annuloplasty band anchored between right and left fibrous trigones (Figure 2). Anterior leaflet pathology is routinely corrected by resuspension using artificial neochordae or triangular resection

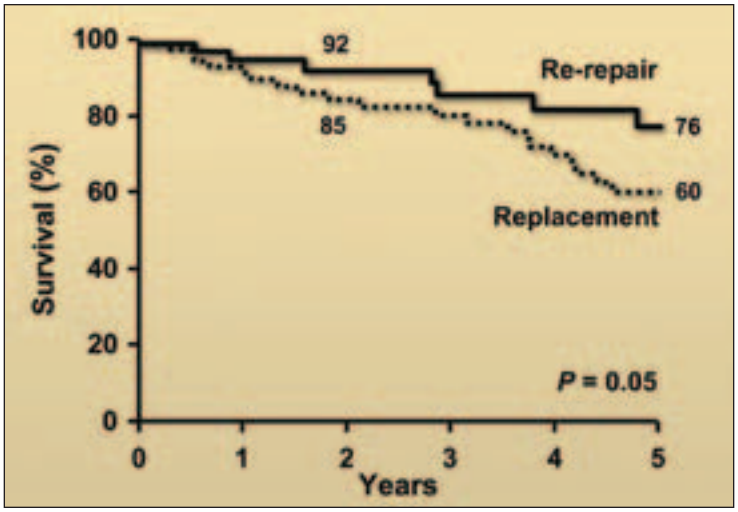

Figure 4. Late survival (>30 days or after discharge from the hospital) after mitral valve re-repair or replacement at reoperation for recurrent MR. The late survival associated with mitral valve re-repair is greater than that seen after mitral replacement (mortality HR for re-repair, 0.49; *P*=.05 vs valve replacement).

and is also protected with a posterior annuloplasty band (Figure 3). Bileaflet disease is addressed using a combination of these techniques. With simplified methods of leaflet repair and annuloplasty support, the risk of reoperation after correction of posterior leaflet prolapse at Mayo Clinic Rochester is approximately 0.5% per year, and rates of reintervention after repair of anterior or bileaflet prolapse are similarly low (1.6% and 0.9% per year, respectively). Indeed, the durability of mitral repair for all leaflet prolapse subsets in the current era is similar to that seen after mitral valve replacement (0.74% per year overall).

Summary

Medical management of patients with severe MR awaiting the development of severe symptoms, atrial fibrillation, pulmonary hypertension, or deterioration in LV size or function invites a high incidence of complications postoperatively and portends poor long-term survival. "The best early and late results are obtained after early mitral valve repair in patients with no or minimal symptoms and normal ventricular geometry," says Dr Suri. "Accordingly, we advise early operation for patients with severe MR who have reparable valves, preferably before the development of symptoms or LV dysfunction" (Figure 4).

New imaging and shafted instrument technology allow for minimally invasive operative techniques. Mayo Clinic Rochester cardiovascular surgeons can now perform port access or thoracoscopic mitral valve repair surgery through small incisions in the right side of chest, thereby avoiding a midline sternotomy in appropriate candidates. Upcoming articles in *Cardiovascular Update* will review minimally invasive treatment of valvular heart disease and the application of robotic-assisted thoracoscopic techniques to mitral valve repair.

Update on Left Ventricular Assist Devices

Cardiovascular Surgery

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Soon J. Park, MD

Heart failure is one of the most common conditions treated; it affects more than 5 million people in the United States and accounts for more than 250,000 deaths annually. Progress has been made in the medical treatment of these patients. Cardiac resynchronization therapy has provided additional quality of life and longevity for some patients. However, many patients with heart failure have progressive symptoms and face a dismal prognosis. The expected survival in patients with persistent New York Heart Association class IV heart failure is less than 25%.

Heart transplantation is an effective treatment for those with advanced heart failure, but it has a rather limited impact epidemiologically. Currently about 2,400 donor hearts yearly become available in the United States, in contrast to the nearly 100,000 patients who would potentially benefit from transplantation. Recognizing this problem, National Institutes of Health scientists and physicians have devoted considerable time and effort to developing cardiac replacement therapy since the 1960s. "Even though we are still far from the original goal of developing a fully implantable, totally artificial heart for long-term support, we have made great progress in the field of left ventricular assist devices (LVADs)," says Soon J. Park, MD, a cardiovascular surgeon at Mayo Clinic Rochester. "LVAD support alone can provide

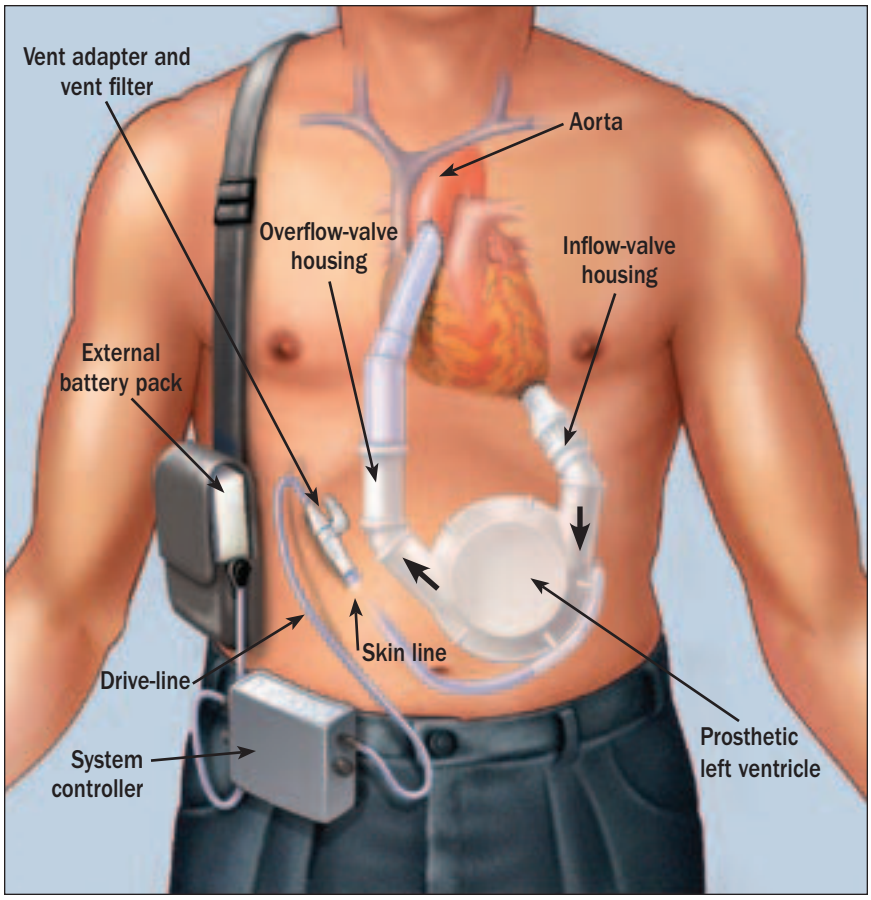


Figure 1. Components of LVAD. The inflow cannula is inserted into the apex of the left ventricle, and the outflow cannula is anastomosed to the ascending aorta. Blood returns from the lungs to the left side of the heart and exits through the left ventricular apex and across an inflow valve into the prosthetic pumping chamber. Blood is then actively pumped through an outflow valve into the ascending aorta. The pumping chamber is placed within the abdominal wall or peritoneal cavity. A percutaneous drive line carries the electrical cable and air vent to the battery packs (only the peak on the right side is shown) and electronic controls, which are worn on a shoulder holster and belt, respectively.

Figure 2. HeartMate-II LVAD with axial flow rotor.

adequate hemodynamic flow in more than 80% of patients with profound heart failure."

One of the first prototypes of LVAD that proved acceptable in the clinical setting is a pulsatile pump known as the HeartMate-XVE (Figure 1). This pump was initially used as a shorter-term support device, bridging patients to heart transplantation. A prospective randomized clinical trial (Randomized Evaluation of Mechanical Assistance for Treatment of Congestive Heart Failure [REMATCH]) tested the hypothesis that long-term LVAD treatment would improve survival and quality of life compared with optimal medical therapy for patients with advanced heart failure. The trial demonstrated a 2-fold survival increase and significantly improved quality of life in patients who were treated with LVADs compared with optimal medical management.

These findings set the stage for LVAD use as a long-term support, "destination therapy." However, it also became clear that there was room for improvement. Early mortality of about 20% was independent of treatment and seemed to reflect the patients who were moribund and too sick to be helped with any therapy. LVAD durability was limited to 1 to 2 years and was not particularly comfortable for patients.

The technology platform for newer LVADs has changed from a pulsatile pump to a continuous flow pump design (Figure 2). Axial rotary pumps are used to support forward flow in supporting circulatory systems. These axial flow devices are much smaller than pulsatile pumps, are expected to last 5 to 7 years, and have reduced morbidity and mortality after surgical implantation. A clinical trial involving the axial flow pump has demonstrated improved survival and quality of life compared with pulsatile pumps as bridge therapy to heart transplantation, and a second clinical trial of these LVADs as destination therapy is ongoing.

Today, the expected survival after LVAD implantation is as high as 95% at 30 days and 70% to 80% at 2 years at Mayo Clinic Rochester. This is a vast improvement for patients facing 1-year survival of less than 25%. Application of LVAD therapy for patients with advanced heart failure, not yet moribund, would result in a quicker surgical recovery and a shorter hospital stay. These patients would be expected to enjoy improved quality of life for many more years on LVAD support.

Mayo Clinic Rochester has assembled a multidisciplinary team, including nurses, device coordinators, nutritionists, physical therapists, social workers, psychiatrists, cardiologists, and cardiovascular surgeons, to provide the most comprehensive medical and surgical treatments for patients with congestive heart failure. Experts from all pertinent disciplines evaluate patients and recommend the most appropriate therapy from all the available options: newer drugs to optimize medical management, cardiac resynchronization therapy with or without a defibrillator, revascularization, valve repair or replacement, heart transplantation, or LVAD implantation.

Many patients who had advanced heart failure are now able to live near-normal lives with the benefit of LVAD support. "The future for our patients with advanced heart failure is hopeful and promising, and we look forward to taking that journey with our patients and their physicians," says Dr Park.

Himeshkumar V. Vyas, MD (right), completed his pediatric cardiology fellowship at Mayo Clinic Rochester and joined the Division of Cardiology at Arkansas Children's Hospital in Little Rock. Ben Eidem, MD (left), is director of the pediatric cardiology fellowship at Mayo Clinic Rochester.

American Heart Association 2007 award recipients include Rick A. Nishimura, MD (left), recipient of the 2007 Laennec Clinician/Educator Lecturer award; Robert L. Frye, MD (center), recipient of the Distinguished Achievement Award; and David R. Holmes, Jr, MD (right), recipient of the 2007 James B. Herrick Award.

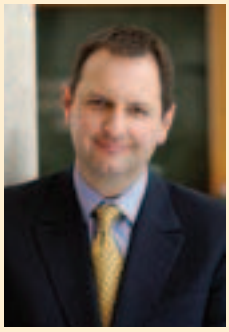
Samuel J. Asirvatham, MD

Rick A. Nishimura, MD

John C. Burnett, Jr, MD

Division of Cardiovascular Diseases Teacher of the Year awards: Recipients of the 2007 Teacher of the Year Awards presented by the Mayo Clinic Rochester cardiovascular fellows are Samuel J. Asirvatham, MD, Peter A. Brady, MD, Krishnaswamy Chandrasekaran, MD (not pictured), and Rick A. Nishimura, MD.

John C. Burnett, Jr, MD, has been named the Marriott Family Cardiovascular Research Professor. This named professorship is awarded to a leading cardiovascular researcher who excels at translational research.



Peter A. Brady, MD

William K. Freeman, MD

Arshad Jahangir, MD

Department of Medicine 2007 Teacher of the Year awards: Recipients of the 2007 Teacher of the Year Awards presented by the Mayo Clinic Rochester internal medicine residents are Peter A. Brady, MD, and William K. Freeman, MD.

Arshad Jahangir, MD, was honored as a recipient of the 2007 William B. Abrams Award in Geriatric Clinical Pharmacology by the American Society for Clinical Pharmacology and Therapeutics at their annual meeting in March 2007.

Gurpreet S. Sandhu, MD, PhD

Peter C. Spittell, MD

Gurpreet S. Sandhu, MD, PhD, and Peter C. Spittell, MD, have received the Mayo Clinic Individual Award for Excellence. This award recognizes those who serve as role models to other Mayo employees by consistently setting high standards for themselves and look at how their work affects others and Mayo as an organization. Recipients display commitment to quality, respect for others, positive attitudes, and dedication by being supportive of Mayo's goals and principles. This award can be earned only once during a Mayo career.

A. Jamil Tajik, MD (left), cardiologist at Mayo Clinic Arizona, shown here with Robert L. Frye, MD. Dr Tajik presented the 11th annual Robert L. Frye Lecture.

Upcoming Courses

Continuing Medical Education, Mayo Clinic

To request additional information or to register, unless noted otherwise, please call 800-323-2688, e-mail cme@mayo.edu, or visit www.mayo.edu/cme.

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Mayo Clinic Nutrition in Health and Disease
Nov 8-9, 2007, San Francisco, CA

Genomics in Everyday Medical Practice
Nov 9-10, 2007, Miami Beach, FL
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Update in Hospital Medicine 2007
Nov 14-17, 2007, Tucson, AZ
Phone: 480-301-4580

Pulmonary Hypertension Update 2007
Dec 1, 2007, Jacksonville, FL
Phone: 800-462-9633; e-mail: cme-jax@mayo.edu

Ethical Dilemmas Throughout the Medical Spectrum
Feb 6-8, 2008, Rochester, MN

Mayo Clinic Interactive Surgery Symposium
Feb 10-15, 2008, Wailea Beach, HI
Phone: 480-301-4580; e-mail: mcs.cme@mayo.edu

33rd Annual Cardiovascular Conference at Snowbird
Feb 19-23, 2008, Snowbird, UT

Arrhythmias and the Heart
Mar 10-13, 2008, Kauai, HI
Phone: 800-283-6296; e-mail: cvcme@mayo.edu

Mayo Echocardiography Review Course
Mar 15-18, 2008, Rochester, MN

Controversies in Cardiovascular Disease
May 3-4, 2008, St. Paul, MN

Valvular Heart Disease: New Strategies
May 5-7, 2008, Las Vegas, NV
Phone: 507-266-0677; e-mail: cvcme@mayo.edu

T. Jared Bunch, MD, fellow in cardiac electrophysiology at Mayo Clinic Rochester, is a recipient of the 2007 Mayo Brothers Distinguished Fellowship Award. Recipients of this annual award are selected on the basis of outstanding clinical performance, humanitarian features, and outstanding scholarly activity. Dr Bunch also received the Donald C. Balfour Alumni Award for Meritorious Research, which recognizes outstanding research by a resident in the Mayo School of Graduate Medical Education.

Continuing Medical Education, Cosponsored With American Society of Echocardiology

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17th Annual Cases in Echocardiography
Oct 24-27, 2007, Napa Valley, CA

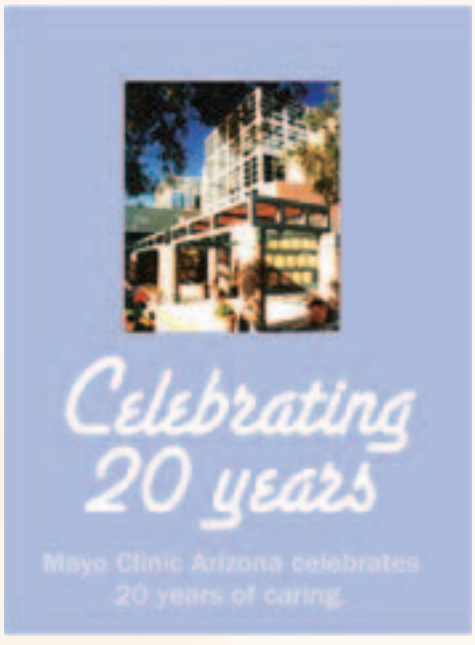
Echo Hawaii 2008
Jan 28-Feb 1, 2008, Big Island, HI

Other Educational Opportunities

American Heart Association Scientific Sessions
Nov 4-7, 2007, Orlando, FL
Phone: 800-242-8721

ACC.08: 57th Annual Scientific Session of the American College of Cardiology and 3rd Annual Innovation in Intervention: i2 Summit
Mar 29-Apr 1, 2008, Chicago, IL
Phone: 202-375-6000

American Society of Echocardiography 19th Annual Scientific Sessions
Jun 7-11, 2008, Toronto, ON
Web site: www.asecho.org



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