

Aortic Valvuloplasty

The state of the art and an introduction to percutaneous aortic valve technology.

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In the US, at least 50,000 open heart aortic valve replacement (AVR) procedures are performed annually to treat severe aortic stenosis (AS), which affects between 2% and 4% of adults older than 65 years.^{1,2} AVR is the most common valve replacement procedure performed and, other than coronary artery bypass grafting (CABG), is the most common open heart procedure. Atherogenic lipoprotein absorption, chronic inflammation, and shear and compressive bending stresses affect gradual intrinsic calcification of the valve leaflet extracellular matrix, resulting in the progressive stiffening of the leaflet with increased impedance to left ventricular ejection.³ Calcific AS affects an estimated 2% to 9% of the elderly population.¹ Adults having a congenital bicuspid aortic valve may present with asymptomatic or symptomatic AS up to 2 decades sooner than adults having a normal tricuspid aortic valve. A systolic ejection murmur with a loud, late-peaking, systolic murmur radiating into the carotid territory and a second heart sound support an initial diagnosis of severe AS.⁴

Once diagnosed, AS progresses with an average increase in aortic jet velocity of .3 m/s per year, a mean pressure gradient increase of 7 mm Hg per year, and a decrease in aortic valve area of .1 cm² per year.⁵ One study of asymptomatic patients with AS found that outflow velocities >4 m/s resulted in symptomatic AS in 38% of the patients at 2 years and 79% of the patients after 3 years.⁶ Patients with asymptomatic AS and significant hemodynamic abnormalities will develop symptomatic AS within 5 years of initial diagnosis.⁷ Without treatment, patients with severe AS have a life expectancy of <5 years. One third of patients with a failing aortic valve are considered high risk for conventional AVR, and another one third are simply refused AVR as a treatment option.

Significant industry-wide improvements in guide

catheter, guidewire, dilatation balloon, and vessel closure technologies have allowed a conservative resurgence in aortic valvuloplasty as a treatment option for a select group of patients presenting with severe lifestyle-limiting AS—especially individuals with significant comorbidities precluding an otherwise very successful surgical AVR. The advent of percutaneous aortic valve replacement (PAVR) technology is on the horizon; however, feasibility study completion and subsequent larger randomized clinical investigations of third- and fourth-generation devices must be completed before this less-invasive approach for treating severe AS can be offered as an alternative to surgical AVR or, in the case of the inoperable patient, as an acceptable treatment option. At present, balloon aortic valvuloplasty (BAV) and PAVR are indicated for a select group of patients considered unsuitable for surgery yet in dire need of palliative treatment to improve their quality of life.

ETIOLOGY OF AORTIC STENOSIS

There are three pathologic types of aortic stenosis. Congenital aortic stenosis occurs when there is incomplete embryologic separation of cusp tissue. There may also be inadequate development of one of the cusps. This results in the so-called unicuspid valve with a small, off-centered orifice. The valve tissue remains soft and pliable. Rheumatic AS includes fusion of the aortic cusps along with fibrocalcific nodular deposits on the aortic side of the valve. These valves do not open or close well, and stenosis is often associated with insufficiency. Degenerative AS is due to the development and progression of fibrocalcific nodules on the aortic side of the valve. There is no fusion of the commissures. This form of degeneration is generally relegated to the seventh to ninth decade of life in the otherwise normal tricuspid

aortic valve. Subtle changes in laminar flow predispose the congenitally bicuspid aortic valve to these changes in the fourth to seventh decade of life. Currently, cardiologists in the US deal primarily with the degenerative fibrocalcific form of AS.

The mechanism of BAV in degenerative AS involves compressing the fibrocalcific nodules between an inflated balloon and the aortic root. There is tearing of the fibrotic elements in the nodules and, to a lesser degree, some stretching of the aortic root. This results in an improved compliance of the nodule-laden cusps so that the acceleration of LV outflow results in a larger aortic valve orifice. It is not uncommon for the fibrotic elements to become re-established, which explains the high restenosis rate for this procedure. Overaggressive dilation has the potential to separate a cusp from the valve ring, drive a calcified spicule through the aorta, and/or tear the aortic ring itself, thus creating an ominous clinical result.

It should be emphasized that surgical aortic valve replacement is the appropriate treatment for symptomatic AS. At best, BAV should be considered a palliative procedure with typical efficacy of 3 to 6 months. The presence of prohibitive operative risk alone may not be sufficient to justify BAV, given the high restenosis rate at 6 months. Ideally, the BAV procedure should be used as a temporary bridge to another more definitive procedure.

BALLOON AORTIC VALVULOPLASTY

BAV was first reported in 1984.⁸ Subsequent registry studies investigated the safety and durability of the procedure in treating patients with severe symptomatic AS.⁹⁻¹² The short-term results demonstrated safety and efficacy, but the longer-term results were less supportive of palliative efficacy and consistently concluded that although the mortality rate was low, there was substantial morbidity.¹³ BAV typically increases stenotic valve area to between .7 cm² and 1.1 cm², which relieves the symptoms of AS, but is significantly less than the valve area achieved after AVR.¹⁴

The National Heart, Lung, and Blood Institute (NHLBI) 674 patient registry determined that high-surgical-risk elderly (83% were >70 years of age) patients having reasonable left ventricular function did achieve improvement in symptoms at 30 days after BAV.¹⁵ This particular patient population was tracked for 3 years; the overall survival was 55% at 1 year, 35% at 2 years, and 23% at 3 years.¹⁶ The majority of deaths (34%), classified by an independent review committee, were attributed to congestive heart failure. Symptom improvement at 2 years was reported by 61% of the patients. An important outcome of this study was the definition of a lower-risk subgroup of patients: those having normal left ventricular systolic

function and mild clinical functional limitation. The lower-risk subgroup had a 36% survival rate at 3 years versus 17% survival for patients having impaired systolic function or moderate-to-severe functional limitations. The NHLBI study and other investigations were conducted 15 years ago when ancillary device technologies were appreciably less advanced than the current generation of support catheters, balloon catheters, steerable guidewires, and closure devices.

Agarwal et al presented contemporary data for 212 consecutive nonsurgical AS patients ranging in age from 59 years to 104 years.¹⁷ The study objective was to determine the symptom relief and survival rate with single or repeat BAV in a patient population having a prohibitive risk for surgical AVR. BAV was performed at the index procedure to obtain a postprocedure transaortic pressure gradient at least 30% lower than the baseline gradient. Single or incremental valvuloplasty inflations were performed to achieve the desired gradient reduction. Mean patient follow-up was 32±18 months, during which 24% of the patients received a second BAV, and 9% required three BAV procedures. The duration of symptom palliation after one, two, or three BAV procedures was 18±3 months, 15±4 months, and 10±3 months, respectively. Survival rates at 1 year, 3 years, and 5 years after the procedure were 64%, 28%, and 14%, respectively.

Another recently reported study of BAV to treat AS in high-risk patients presented similar acceptable results for a group of 80 consecutive patients.¹⁸ All patients in the study were at least 60 years of age, with a mean age of 81±10 years; a remarkable 23% of the patients were over the age of 90 years. Patients with cardiogenic shock or an ejection fraction <30% represented 20% and 38% of the population, respectively. All patients had clinical symptoms attributed to severe AS and a documented aortic valve area of ≤1 cm², with a mean pressure gradient of ≥30 mm Hg. Patients having more than moderate aortic regurgitation were excluded from the study. Repeat BAV was required in several patients, and the long-term survival was followed for a mean of 3±2 years. Thirteen patients required a second BAV procedure, two patients underwent three dilatation procedures, and one patient returned four times for BAV. A high-risk EuroSCORE was recorded for 98% of the patients. There were no procedure-related deaths and the in-hospital and 1-, 2-, and 3-year survival rates were 94%, 56%, 38%, and 29%, respectively.

BAV should be considered as a viable treatment option for the high-surgical-risk patient with AS or the patient who declines conventional AVR. Symptom relief is immediate, and short- to long-term palliative results are certainly acceptable from a perspective of improved quality-of-life assessments.

TABLE 1. ACC/AHA CLASSIFICATION OF AORTIC STENOSIS SEVERITY IN ADULTS

Aortic Stenosis Severity	Antegrade Jet Velocity (m/s)	Mean Gradient (mm Hg)	Aortic Valve Area (cm ²)	Valve Area Index (cm ² per m ²)
Mild	2.6-3	<25	>1.5	
Moderate	3-4	25-40	1-1.5	
Severe	>4	>40	<1	<.6

2006 ACC/AHA Practice Guidelines.

INDICATIONS FOR BAV

A decrease in exercise tolerance or the occurrence of exertional dyspnea, angina, congestive heart failure, arrhythmia, or syncope requires prompt diagnostic laboratory evaluation. Diagnosis and severity of AS are confirmed through echocardiography with quantification of left ventricular hypertrophy, diastolic and systolic dysfunction, or the presence of other valvular disease.¹⁹ Two-dimensional Doppler echocardiography accurately measures maximum jet velocity, mean and peak systolic valvular gradients, and valve area. Cardiac catheterization with coronary angiography frequently complements echocardiography findings, especially if a nonsurgical approach to treatment is under consideration. Current guidelines recommend AVR surgery for symptomatic patients with AS, with the exception of patients having serious comorbidities, making them a high surgical risk. This increasingly large subset of elderly patients may be best treated by BAV or, in the future, by PAVR. Operative-risk assessment calculators are available at Web sites for the Society of Thoracic Surgeons (www.sts.org) and the European System for Cardiac Operative Risk Evaluation (www.euroscore.org). Current guidelines indicate an average 3% to 4% perioperative mortality risk rate for AVR only and a 5.5% to 6.8% mortality risk rate for AVR plus a coronary artery bypass graft procedure.⁵ Patients over the age of 65 years have an average in-hospital mortality rate for AVR of 8.8%.

In accordance with the ACC/AHA 2006 Practice Guidelines for the Management of Patients with Valvular Heart Disease, adult patients presenting with severe stenotic aortic valve disease should have a mean jet velocity >4 m per second, a mean pressure gradient >40 mm Hg, a valve area <1 cm², and a valve area index <.6 cm² per m². Guidelines for grading the severity of aortic valve disease are presented in Table 1.

High-surgical-risk patients include those presenting with severe left ventricular hypertrophy; severe left ventricular dysfunction; cardiogenic shock; ventricular tachycardia; advanced age; significant lung disease, such as chronic obstructive pulmonary disease; malignancy; or severe multivessel coronary artery disease. BAV currently

is considered a reasonable bridge to surgery in adult patients with AS considered high risk for AVR or as reasonable palliation for adult patients with AS who are non-surgical candidates, as described. Published clinical data have previously not supported the use of BAV as a durable treatment for AS with only a moderate initial decrease in transvalvular pressure gradient and restenosis within 12 months for most patients. The utility of BAV should not be underestimated because it may allow significant improvement in the quality of life for inoperable patients with symptomatic AS or, as illustrated in a case study, be a treatment option before another noncardiac surgical procedure that could not be performed with severe AS.

The anatomic considerations in assessing BAV candidates include having good vascular access that will allow a 14-F femoral sheath, minimal or mild aortic insufficiency, and it is generally preferred to have a mean aortic gradient of at least 40 mm Hg. The ability to generate a significant gradient has the clinical implication of preserved cardiac reserve and is associated with a more predictable resolution of symptoms after the procedure. The patients with low gradients and low ejection fraction, despite a small-calculated orifice area, are less likely to realize a clinical improvement. Two case studies are presented to demonstrate how BAV is utilized in our practice.

CASE STUDIES

Case 1

The first patient is an 80-year-old woman with a history of hypertension, hyperlipidemia, coronary artery disease, AS, and recurrent symptoms of congestive heart failure. Cardiac catheterization at an outlying hospital demonstrated severe tortuosity of the aorta and mild coronary artery disease, including severe stenosis of a diagonal branch. Her left ventricular systolic function was normal, and mild aortic insufficiency was identified. Her aortic valve area by catheterization was .7 cm² with a 60-mm peak systolic gradient between the left ventricle and the aorta. The patient was referred for AVR but refused. Symptoms of congestive heart failure worsened over a relatively short period of time, and combined with severe



Figure 1. Severe tortuosity of the ascending aorta of patient 1; this anatomy may preclude use of a retrograde approach for BAV.

degenerative joint disease of the right hip, she became wheelchair bound. Right hip replacement surgery was considered; however, the orthopedic surgeon refused to perform the operation because of her existing coronary artery disease and severe aortic stenosis.

I saw this patient as a referral, and, after discussion with her and her family, she remained adamant about not having an AVR procedure but very much wanted to have a hip replacement to enable her to walk and resume her active lifestyle. I offered her an option of BAV and explained the associated risks; the procedure was agreed to, and she was admitted for palliative BAV.

At the time of her cardiac catheterization, the initial attempt at advancing a pigtail catheter into the left ventricle failed because of severe tortuosity in the ascending aorta (Figure 1). A 6-mm X 90-cm Shuttle Sheath (Cook Medical, Bloomington, IN) was placed into the aortic arch and, with the support of the sheath, the pigtail catheter was passed across the aortic valve to measure ventricular pressure and determine a baseline transvalvular gradient. A right heart catheterization was also performed. Having established baseline pressures and a transvalvular gradient of 60 mm Hg, a .035-inch Super Stiff Amplatz guidewire (Boston Scientific Corporation, Natick, MA) with a large curve was placed into the left ventricle. An additional 4-F arterial sheath was placed into the left femoral artery for continued pressure measurement, and the Swan-Ganz catheter (Hospira Corporation, Lake Forest, IL) was left in place for monitoring pulmonary artery and capillary wedge pressures during the BAV.

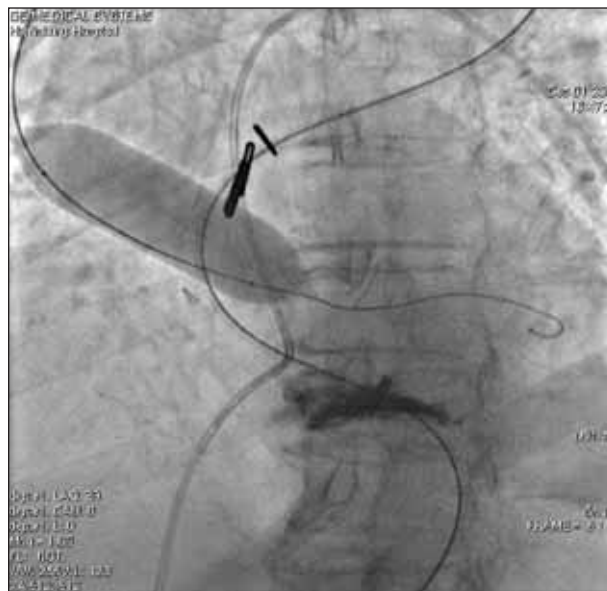


Figure 2. Balloon valvuloplasty using a 22-mm X 60-mm Z-Med II balloon (B. Braun Medical Inc., Bethlehem, PA); seven inflations were performed.

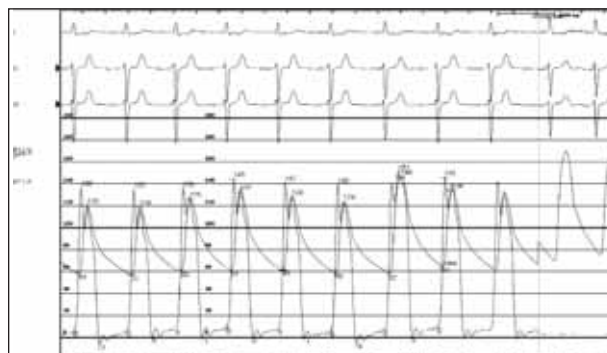


Figure 3. Simultaneous LV and Ao pressure recordings following BAV (X 7) in the patient from case 1.

Seven balloon inflations were performed across the aortic valve using a 22-mm X 60-mm Z-MED II balloon (Figure 2). After BAV, the transvalvular systolic pressure gradient was ≤ 16 mm, ventricular ejection appeared excellent, and the aortic valve insufficiency remained mild (Figure 3). Right groin hemostasis was achieved using a Prostar XL percutaneous suture-mediated closure device (Abbott Vascular, Santa Clara, CA).

The patient did extremely well after the procedure and was released 24 hours later with apparent complete resolution of her heart failure symptoms. The patient subsequently underwent right hip replacement 1 month later with no complications and was transferred to a rehabilitation facility. At 6-month follow-up, the patient remained completely symptom free of heart failure, angina, or syn-



Figure 4. Porcelain aorta of patient 2 as observed during original diagnostic catheterization.

cope. The echocardiogram performed before the 6-month follow-up office visit estimated the aortic valve area was 1.1 cm^2 . The left ventricular systolic function remained normal, and there was only trace aortic insufficiency.

Case 2

The second patient is an 88-year-old woman with a history of hypertension, asthma, and severe AS since 2002. The patient had an episode of syncope in 2002, which led to cardiac catheterization. At the time, she was found to have severe AS with a calculated valve area of $.5 \text{ cm}^2$, normal left ventricular systolic function, and a mean aortic valve gradient of 50 mm Hg. The coronary arteries were without significant disease except for severe stenosis in a very small diagonal branch. Eggshell calcification of the ascending aorta was also noted at angiography (Figure 4). The patient was evaluated by cardiac surgery for AVR and was considered a high surgical risk because of significant calcification in the ascending aorta. In addition, the patient refused to undergo open-heart surgery.

The patient subsequently had occasional episodes of dizziness and syncope. In January 2007, she had syncope while driving and fortunately was not involved in a motor vehicle accident. The patient was admitted for evaluation and had a repeat echocardiogram, which identified normal left ventricular systolic function, moderate mitral regurgitation, an aortic valve area of $.7 \text{ cm}^2$, a mean gradient of 61 mm Hg, and mild aortic insufficiency. The left ventricle was hypertrophied. The patient was again evalu-

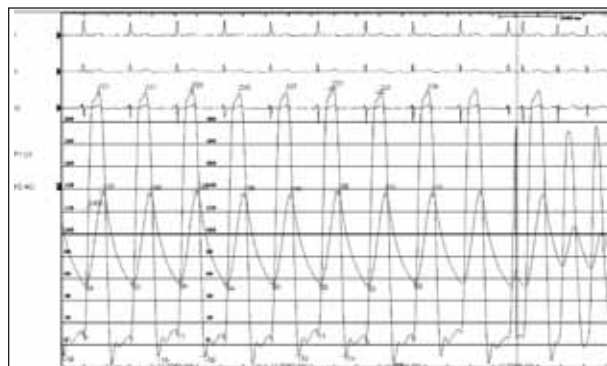


Figure 5. Simultaneous LV and aortic pressure recordings as recorded during diagnostic cardiac catheterization.



Figure 6. Fully inflated 22-mm X 60-mm Z-Med II balloon during BAV of the patient from case 2.

ated by cardiac surgery and declined a surgical approach to resolving her AS. The patient was referred to me for discussion of an alternative approach to treating her AS. She subsequently agreed to undergo a cardiac catheterization at Harrisburg Hospital and consider BAV as a treatment option.

Diagnostic right and left heart catheterizations were performed. Mean pulmonary arterial pressure was 20 mm Hg, and the pulmonary capillary wedge pressure was 13 mm Hg. The simultaneous pressure gradient between the aorta and the left ventricle was measured using a 6-F Langston dual lumen pigtail catheter (Vascular Solutions, Minneapolis, MN). The peak-to-peak gradient across the aortic valve was 90 mm Hg (Figure 5). The mean gradient

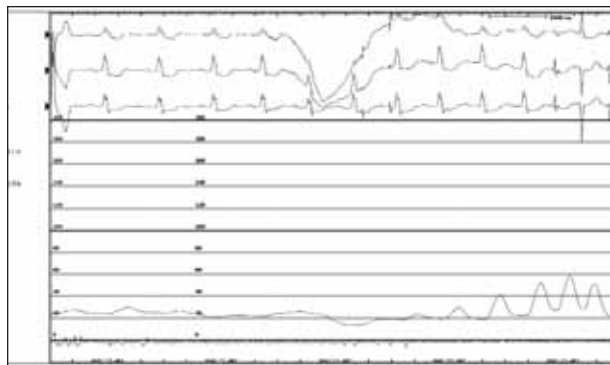


Figure 7. During BAV of the patient from case 2, there was a significant decrease in blood pressure during aortic valvuloplasty.

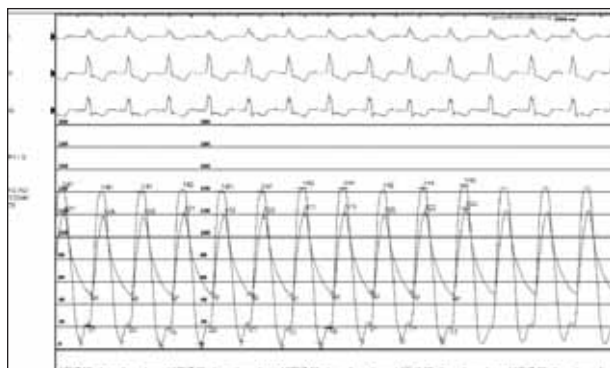


Figure 8. Simultaneous LV and aortic pressure traces demonstrating significant reduction in the transvalvular pressure gradient after BAV in the patient from case 2.

was 81 mm Hg, and a calculated aortic valve area of .3 cm^2 was recorded. The ascending aorta was heavily calcified. Left ventricular systolic function was normal, and there was mild coronary artery disease. Because of the patient's recurrent syncope, aortic valvuloplasty was offered as a palliative option.

The patient was brought to the cardiac catheterization laboratory in a staged fashion. First, right common femoral access was obtained, and a right common femoral arteriography was performed. A 10-F Prostar XL percutaneous suture-mediated closure device (Abbott Vascular, Redwood City, CA) was deployed for preclosure of the femoral arteriotomy. A Swan-Ganz catheter was placed. An additional 4-F arterial sheath was placed in the left common femoral artery for arterial pressure measurement. Using a 6-F AL 1 catheter (Cordis Corporation, a Johnson & Johnson company, Miami, FL) and a straight-tip wire, the aortic valve was successfully crossed. A .035-inch Amplatz stiff guidewire was placed with a J-shaped loop into the left ventricle. A 22-mm X 60-mm Z-MED II



Figure 9. Edwards SAPIEN THV by Edwards Lifesciences (26-mm and 23-mm size).

balloon was placed across the aortic valve, and multiple inflations were performed (Figure 6). The patient became asystolic and very hypotensive (Figure 7) during valvuloplasty and recovered gradually. Again, simultaneous pressures were measured within the left ventricle and aorta, and her pressure gradient was 20 mm Hg (Figure 8). The aortic valve area was calculated to be .7 cm^2 . The ascending aortogram demonstrated only minimal aortic insufficiency. Hemostasis was achieved in the right common femoral artery using a percutaneous suture-mediated closure device as noted above.

The patient was discharged the next day without any complications. She had a repeat echocardiogram in the office 2 weeks after the procedure at which time the aortic valve area was 1.3 cm^2 with a mean gradient of 23 mm Hg. Left ventricular systolic function remained stable. She reported no angina, heart failure, or syncope since the BAV procedure and admitted to a significant improvement in her overall well-being. The patient will have close follow up with us with serial echocardiography and observation for clinical symptoms of aortic stenosis.

PROCEDURAL RECOMMENDATIONS FOR SUCCESSFUL RETROGRADE AORTIC VALVULOPLASTY

Procedure considerations need to accommodate issues relative to the fact that candidates for BAV tend to be elderly and fragile. Meticulous access-site management will greatly reduce procedure-related morbidity. The retrograde approach is favored for its technical simplicity. A 6-F sheath is placed in the mid common femoral artery. On the contralateral side, a femoral venous sheath is placed to allow passage of a Swan-Ganz catheter into the pulmonary artery. A 4-F sheath is placed in the contralateral femoral artery for the purpose of arterial pressure monitoring. A 10-F percutaneous vascular closure device is used to place two sutures in the common femoral access site and is then



Figure 10. Transfemoral approach for crossing the stenotic aortic valve. RetroFlex transfemoral delivery system by Edwards Lifesciences.



Figure 11. Mini thoracotomy for transapical delivery of the Ascendra delivery system by Edwards Lifesciences.

exchanged for a 14-F long sheath. It is important to understand that percutaneous vascular closure is not possible in every patient. Femoral arteriography with digital subtraction should be performed to assess the candidacy of percutaneous suture-mediated closure. It is common to administer 5,000 U of heparin for anticoagulation. A pigtail catheter is placed into the left ventricle using standard techniques. A .035-inch X 260-cm length extra stiff J-tip guidewire is passed across the aortic valve and used as a rail to allow passage of the balloon across the aortic valve. Balloon selection includes diameters of 18 mm, 20 mm, 22 mm, and 23 mm and lengths of 4 cm and 6 cm. A 22-mm X 6-cm balloon is a common selection. The balloon is prepped with a mixture of 25% ionic dye and 75% saline to provide the best balance of viscosity and opacification. The balloon requires 30 mL to 40 mL for full inflation. Combining a 30-mL and 20-mL syringe by means of a three-way high-pressure stopcock affords the rapid hand inflation/deflation needed for dilation. Generally, two inflations across the valve are sufficient. Each inflation is 5 to 10 seconds in duration. Recently, temporary RV pacing at a rate of 160 bpm to 220 bpm has been employed during balloon inflations to eliminate the tendency for the LV to eject the balloon. Systemic blood pressure commonly falls to 0 mm Hg during inflation and recovers over 20 to 30 seconds after balloon deflation. The balloon is exchanged for a pigtail catheter for final pressure measurements. Root aortography is done to assess the degree of aortic insufficiency created. Heparin is partially reversed with protamine. The 14-F sheath is removed, and the preplaced sutures are tied to achieve hemostasis.

Procedure-related trauma is reduced if a single balloon

is utilized. Operators vary in what they will accept as a final result. A residual gradient of <20 mm Hg would be considered very good. Complications include issues related to femoral artery trauma, embolic cerebrovascular events, severe aortic insufficiency, heart block, injury to the aorta, and cardiac perforation.

An antegrade approach to aortic valvuloplasty has also been described. While technically more difficult to perform, better acute valve area results have been reported. The procedure is done via transvenous, transseptal access, so large caliber arterial sheaths are not needed.²⁰

PERCUTANEOUS AORTIC VALVE REPLACEMENT

Efforts to develop a percutaneous replacement heart valve technology were realized in 2002 by the first human percutaneous AVR placement by Cribier et al.²¹ The first-generation stent-valve consisted of three leaflets fabricated from bovine pericardium sewn into a stainless steel balloon-expandable stent. Device delivery required an antegrade transseptal approach necessitating venous access for placement of a 24-F sheath. A transapical delivery system has recently been used for valve deployment and performed by endoscopy through a small left anterior or thoracotomy.²² A retrograde arterial approach is now the preferred route for valve delivery to the aortic annulus with several companies aggressively working on devices having a lower profile for the retrograde transfemoral approach for accurate placement within the aortic annulus. As many as 20 companies are actively developing their own iteration of a percutaneous valve replacement technology.²³

EDWARDS LIFESCIENCES

Edwards Lifesciences (Irvine, CA) has two investigational percutaneous aortic bioprostheses. The Edwards-SAPIEN Transcatheter Heart Valve (THV) (Figure 9) is composed of three bovine pericardial leaflets treated with a TheraFix process and mounted in a balloon-expandable stent. The 26-mm and 23-mm stents are designed for delivery using either a transfemoral (RetroFlex [Edwards] [Figure 10]) or transapical (Ascendra [Edwards] [Figures 11 and 12]) delivery system through 24-F or 22-F sheaths, respectively.

PAVR with this system was performed in a small group of high-surgical-risk elderly (81 ± 6 years) patients and recently reported by Webb.²⁴ The balloon-expandable, stent-mounted equine pericardial valve was delivered using a retrograde approach from the femoral artery. Aortic balloon valvuloplasty preceded valve deployment, and rapid ventricular pacing was employed to reduce cardiac output during stent valve deployment. Valve deployment was successful in 14 of 18 patients with an increase

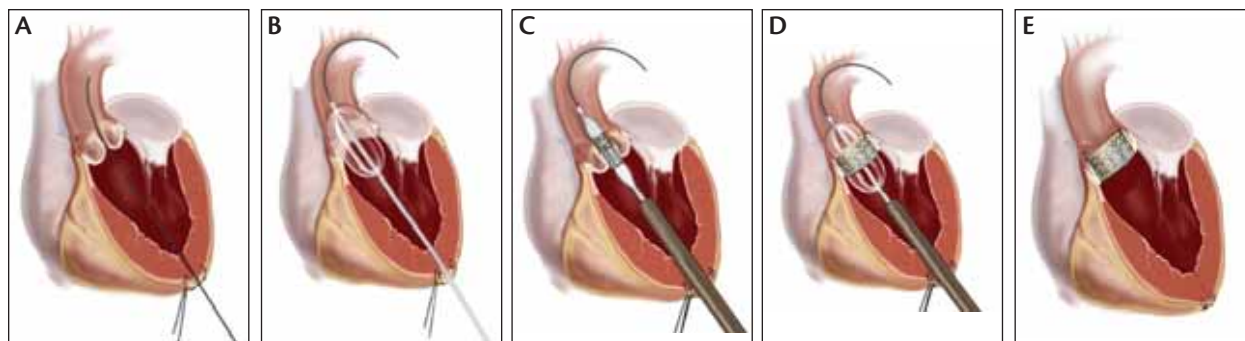


Figure 12. Transapical deployment steps: apical entry (A), predilation (B), stent positioning (C), stent deployment (D), and deployed stent with sutured closure of LV apex (E). Caution: investigational device. Limited by federal (US) law to investigational use. Not available for sale in the US.

in valve area from $.6 \pm .2$ to $1.6 \pm .4$ cm². There were no procedure-related deaths, and 89% of the patients were alive at 75 ± 55 days after the procedure.

An earlier study, using an antegrade transseptal approach and the same Edwards equine pericardial stent valve, reported nearly identical improvement to the valve area after valve deployment and similar survival data out to 8 weeks without signs of heart failure.²⁵ Last year, Cribier and colleagues reported similar results for 27 patients with inoperable AS who were successfully implanted with the Edwards percutaneous heart valve by either an antegrade (n=23) or retrograde (n=4) approach. The aortic valve area for these patients was $\leq .7$ cm², and they were NYHA functional class IV and had severe comorbidities. Hemodynamic and clinical improvement occurred in all patients, and no deaths were attributed to device failure.²⁶

COREVALVE PERCUTANEOUS REVALVING SYSTEM

CoreValve Corporation (Irvine, CA), a privately held company, has developed a percutaneously implantable replacement aortic valve for treatment of patients having a high risk of complications from conventional AVR. The CoreValve ReValving System consists of a porcine pericardial tissue trileaflet valve mounted within a self-expanding multilevel nitinol support frame (Figure 13). The biopros-

theses, designed specifically for percutaneous application, is sutured to the frame. The valve-leaflet pattern and attachment geometry are key to the valve's flow and durability characteristics. The design also optimizes the ability of the pericardium to fold into a smaller delivery catheter without the risk of tissue damage.

Grube et al reported the first use of the CoreValve ReValving System as a PAVR, and investigational studies of the device have been reported by others.^{27,28} Four consecutive patients at high surgical risk for AVR received treatment with the device in Germany in November 2006. The successful procedures were significant in that a truly percutaneous approach was performed, therefore obviating the need for surgical access or repair, and rapid ventricular pacing was not required for successful valve deployment within the aortic annulus. The procedure was completed quickly, and all four patients were discharged from the hospital within a few days of the procedure. A phase 3 clinical trial is underway in Europe with this device, and total enrollment of 88 patients is anticipated.

The current PAVR technique targets a population of patients with several AVR risk factors, including very old age and moderately depressed ventricular function. The surgeon routinely declines this select patient population for AVR, and the patients are left with no option other than a difficult adjustment to a relatively poor quality of

TABLE 2. SUMMARY OF REVALVING PROCEDURES PERFORMED WORLDWIDE*

Time Period	Study Phase	Product Used	Number of Patients
July 2004 to July 2005	First in man	Generation 1 (25 F)	14
August 2005 to August 2006	21-F international trial	Generation 2 (21 F)	65
Ongoing	18-F international trial	Generation 3 (18 F)	88
Total worldwide ReValving System patients			167
*Current data as of April 24, 2007.			

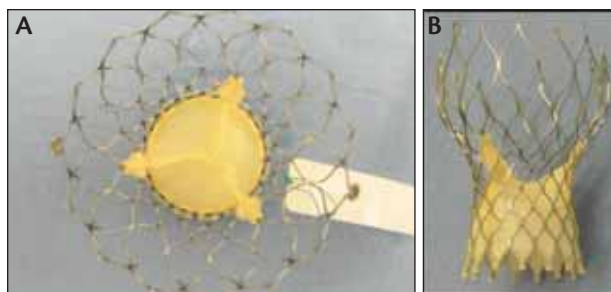


Figure 13. Porcine pericardial tissue valve mounted in self-expanding multilevel support frame (A). The trileaflet valve is centrally positioned within the closed-cell design nitinol stent and designed for supra-annular leaflet function without obstruction to the coronary ostia (B).

life until they succumb to congestive heart failure. Proper patient selection to include viable cardiac function, no worse than mild aortic or mitral valve regurgitation, and acceptable coronary reserve will yield a significant number of patients for whom PAVR will be a welcome alternative to high-risk AVR or no treatment at all. Table 2 presents a summary of clinical experience to date with the CoreValve ReValving System.

The current third-generation device is .035-inch, over-the-wire compatible within an 18-F delivery catheter. The delivery system is intended for a retrograde approach, has a 12-F shaft exhibiting good flexibility for traversing the aortic arch, and employs a dual speed release handle. The small size of the delivery catheter not only improves overall maneuverability but also obviates the need for surgical access to the femoral artery for device insertion. The ReValving System received CE Mark approval in May 2007, and the company intends to expand clinical evaluation at select international centers to further define patient selection criteria and physician training requirements for continued optimal clinical outcomes. The CoreValve ReValving System is not available in the US for clinical trials or commercialization.

TECHNICAL CONSIDERATIONS

Vascular access in elderly patients or any other patient having diseased or small femoral or iliac arteries will challenge a retrograde approach for valve implantation. The alternative approach for stent delivery through a limited incision in the anterior chest and a left ventricular apical insertion may prove more feasible for some of these patients, however, the technique and ancillary equipment will need further improvement. ■

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