Aortic Valve Repair Using a Differentiated Surgical Strategy

Frank Langer, MD; Diana Aicher, MD; Anke Kissinger, Olaf Wendler, MD; Henning Lausberg, MD; Roland Fries, MD; Hans-Joachim Schäfers, MD

Background—Reconstruction of the aortic valve for aortic regurgitation (AR) remains challenging, in part because of not only cusp or root pathology but also a combination of both can be responsible for this valve dysfunction. We have systematically tailored the repair to the individual pathology of cusps and root.

Methods—Between October 1995 and August 2003, aortic valve repair was performed in 282 of 493 patients undergoing surgery for AR and concomitant disease. Root dilatation was corrected by subcommissural plication (n=59), supracommisural aortic replacement (n=27), root remodeling (n=175), or valve reimplantation within a graft (n=24). Cusp prolapse was corrected by plication of the free margin (n=157) or triangular resection (n=36), cusp defects were closed with a pericardial patch (n=16). Additional procedures were arch replacement (n=114), coronary artery bypass graft (n=60) or mitral repair (n=24). All patients were followed-up (follow-up 99.6% complete), and cumulative follow-up was 8425 patient-months (mean, 33±27 months).

Results—Eleven patients died in hospital (3.9%). Nine patients underwent reoperation for recurrent AR (3.3%). Actuarial freedom from reoperation at 5 years was 93%, 95%, and 98%, respectively. No thromboembolic events occurred, and there was 1 episode of endocarditis 4.5 years postoperatively.

Conclusions—Aortic valve repair is feasible even for complex mechanisms of AR with a systematic and individually tailored approach. Operative mortality is low and mid-term durability is encouraging. The incidence of valve-related morbidity is low compared with valve replacement. (Circulation. 2004;110[suppl II]:II-67–II-73.)

Key Words: aortic valve ■ aortic regurgitation ■ root replacement ■ cusp prolapse ■ cusp repair

Reconstruction of the aortic valve for pure aortic regurgitation (AR) has gained increasing interest in the past 10 years. Nevertheless, aortic valve repair has remained a surgical challenge and has been applicable to only a limited proportion of patients. Repair of a tricuspid valve with 3 coaptation lines is more difficult than the bileaflet mitral valve; in addition, different pathologies of aortic root and cusps may contribute to valve dysfunction.1–4 Dilatation of the aortic root is currently the most frequent cause of regurgitation.2–4 Prolapse of cusp tissue in bicuspid anatomy or “floppy” tricuspid aortic valves1 impairs coaptation by a different mechanism, especially in the presence of congenital fenestrations. Rarely, cusp perforations lead to regurgitation through localized tissue defects.5,6 Different techniques have been developed that are commonly targeted at single causes of aortic insufficiency. Valve-preserving aortic replacement has been proposed in different modifications7,8 for AR caused by root dilatation and has become a promising alternative to composite valve graft. Isolated cusp prolapse in tricuspid, and particularly bicuspid, aortic valves without concomitant aortic root dilatation can be repaired with encouraging results1,6,9–14 using plication or triangular resection of cusp tissue. Fenestrations or perforations can be closed with autologous pericardial patches.1,11

So far, these approaches have been applied only in very selected groups of patients with aortic regurgitation. In many patients, however, AR is caused by a combination of both root and cusp pathology.4,15 Currently these patients are still treated with composite replacement by most surgeons, thus exposing the patients to the known valve-related risks,16 such as thromboembolism, anticoagulation-related hemorrhage, and prosthetic valve endocarditis.

We have systematically used reconstructive approaches to either cusp or root pathology and combined them if necessary, thus tailoring the repair to the individual pathology. For patients with moderate root dilatation predominantly at sinutubular (ST) level root remodeling7 was performed. Root ectasia involving the aorto-ventricular (AV) junction was addressed with reimplantation of the aortic valve within a vascular graft.8 Cusp prolapse was corrected whenever relevant using plication of the free margin or triangular resec-

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cusp defects were corrected using autologous pericardium. Repair was undertaken regardless of tricuspid or bicuspid aortic valve anatomy. In this retrospective investigation, we analyzed our results with this differentiated gender (Table 1).

### Materials and Methods

#### Patients

Between October 1995 and August 2003, a total of 493 patients underwent surgery for pure AR with or without concomitant cardiac or aortic disease in our department. Of this total patient population, 282 patients (57.2%) were treated by valve repair and represent the study group. In a large group of these patients (n=186), the primary indication for elective surgery was aortic disease including aneurysm. In the presence of more calcifications or cusp retraction, aortic valve or composite replacement was performed.

#### Operative Technique

In all patients the chest was opened by median sternotomy and the patients were placed on extracorporeal circulation by aortic and right atrial cannulation. After aortic cross-clamping and aortotomy, cardioplegic arrest was induced by infusion of blood cardioplegia directly into the coronary ostia. The entire aortic root was inspected systematically: Diameters of AV junction and ST junction were measured during cardiac arrest, and the morphology and geometry of the aortic cusps were assessed. A decision for aortic valve repair was made whenever the cusp tissue was pliable or limited calcifications were present in a median raphe. In the presence of more calcifications or cusp retraction, aortic valve or composite replacement was performed.

Root dilatation was primarily determined on the basis of intraoperative measurements of ST diameter as a simple surrogate of the more complex dimensions of the root. In all instances, sinus dimensions were at least 5 mm larger than ST diameter. Root dilatation was considered as minimal or mild if ST diameter was <35 mm, moderate if ST diameter was ≥35 mm and AV diameter <30 mm; it was seen as severe in the presence of an AV diameter of ≥30 mm. Subcommisural plication was using Teflon-pledgetted mattress sutures was performed for minimal or mild root dilatation. If ascending aortic replacement was necessary as dictated by ascending aortic diameter, then this was performed with a supracommissural graft, thus providing additional stabilization to the ST junction. For moderate root dilatation root remodeling was performed in typical fashion (Figure 2). The graft size was chosen ~2 mm smaller than the diameter of the AV junction. The Dacron graft (Intergraft; Intervascular) was then tailored creating a sinus-like configuration corresponding to the geometry of the aortic root. In bicuspid valves the tailoring process accommodated the asymmetry of the bicuspid root. In the presence of severe root dilatation or Marfan syndrome (n=9), root replacement was performed with reimplantation of the aortic valve within a vascular graft (Figure 3). The aortic valve was mobilized to the level of the AV junction. The graft size was chosen according to the maximum height measured from the base to the free edge of the leaflets, leaving ~30% to 40% of leaflet height for coaptation. In effect, a 26- or 28-mm graft was used in all patients.

The graft was then anastomosed to the AV junction using transmural mattress sutures. Reimplantation of the native valve was performed using the original technique.

For the assessment of cusp prolapse in tricuspid anatomy, a 7-0 Prolene suture (Ethicon) was passed through the noduli of Arantius and placed under traction to estimate the relative length of all free cusp margins. In bicuspid aortic valves, radial tension was placed on the 2 commissures. Cusp prolapse, ie, excessive length of 1 or more free cusp margins (>3 mm) was corrected by shortening the free cusp margins.
margin using 1 or several Prolene 5-0 or 6-0 (Ethicon) in the central portion of the free margin until identical length of the free margins was achieved (Figure 4). If a median raphe was present with pliable tissue quality, the same technique was used (Figure 1). Triangular resection of the median raphe with reapproximation of the 2 rudimentary cusps was performed in 36 patients if there was extreme redundancy of cusp tissue, fibrosis, or calcification in this particular area, making direct suture adaptation difficult. If there was cusp prolapse in the presence of congenital fenestrations and the cusp tissue appeared friable, the fenestrations on the prolapsing cusp were closed with autologous pericardial patches (Figure 5), attempting to shorten the free margin during this procedure. Additional plication was then performed as necessary. Healed endocarditic perforations were primarily closed using autologous pericardium (Figure 6).

If initial inspection indicated the presence of moderate or more root dilatation, the respective root replacement procedure was performed first, irrespective of the appearance of additional cusp prolapse. After completion of this step, cusp morphology and coaptation were assessed again. Any prolapse becoming evident at this point was then corrected. In the presence of no or mild root enlargement and cusp pathology, the cusps were corrected first, using the techniques described. Subcommissural plication sutures were added after completion of cusp repair. In all instances, aortic valve configuration and cusp coaptation were tested by filling the aortic root with saline.

Concomitant procedures were performed as necessary, eg, coronary artery bypass surgery, mitral valve repair, or arch replacement under hypothermic circulatory arrest (21°C nasopharyngeal temperature for partial arch replacement, 18°C nasopharyngeal temperature for total arch replacement). Additional retrograde cerebral perfusion was applied during circulatory arrest only if marked atherosclerotic debris was found in the aortic arch.

Echocardiographic Surveillance

After weaning from cardiopulmonary bypass (diastolic blood pressure at 70 mmHg) transesophageal echocardiography was performed to determine aortic valve competence (HDI 3000; Advanced Technology Laboratories). A semi-quantitative assessment of the degree of aortic regurgitation was based on the intensity and slope of the regurgitation signal and the relative size of the regurgitation jet in relation to the left ventricular outflow tract.21,22 Postoperative trans-thoracic echocardiography was performed at discharge and after 3, 6, 9, and 12 months, and every 12 months thereafter. In addition to assessment of regurgitation, systolic flow gradients were recorded. All echocardiographic investigations were performed by experienced echocardiographers (F.L., D.A., H.L.). All echocardiographic studies were stored on videotape and additionally interpreted by the consulting cardiologist (R.F.).

Statistics

All data were reviewed retrospectively. Mean values and standard variations were calculated. Actuarial Kaplan–Meier curves were calculated using Graphpad software (Graphpad Prism).

Results

Tricuspid aortic valve anatomy was found in 191 cases; bicuspid anatomy was found in 91 instances. Isolated aortic valve repair, ie, cusp repair without root replacement, was performed in 83 patients and combined with subcommissural plication in 59, and supracommissural aortic replacement was performed in 27 patients (Table 2). Aortic root reconstruction without concomitant cusp repair was performed in 103 individuals, whereas the combination of cusp reconstruction and root reconstruction was required in 96 patients.

Cusp repair included plication of a single cusp (n=105) or 2 cusps (n=49), generalized prolapse with plication of all 3 cusps was only required in 3 patients. Resection of a median raphe was performed in 36 patients with bicuspid anatomy. A pericardial patch was used in 16 patients (endocarditis, n=3; fenestrations, n=13).

The root reconstruction procedure was root remodeling in 175 patients, and reimplantation of the aortic valve was performed in 24 patients. In these patients tricuspid anatomy was present in 144 cases (remodeling, n=121/175; reimplan-
Root reconstruction was combined with cusp repair in 96 patients (remodeling, n=87/175; reimplantation, n=9/24).

Extracorporeal circulation time was 109±48 minutes; myocardial ischemic time was 76±30 minutes. Hypothermic circulatory arrest was used in 114 cases (partial arch replacement, n=94; total arch replacement, n=20), with a mean circulatory arrest time of 19±9 minutes.

Hospital mortality was 3.9% (11/282), 2.9% after elective operations and 10.5% after emergency procedures (Table 2). The causes of death included cardiac failure (n=6), nonocclusive mesenteric ischemia (n=3), fatal stroke (n=1), and pulmonary embolism (n=1). Nine patients (isolated valve repair, n=3; root reconstruction, n=4; combination, n=2) required re-exploration for surgical bleeding. Postoperative atrioventricular conduction disturbance was not observed in any patient. Three patients required an intra-aortic balloon pump for treatment of low cardiac output. Postoperative neurologic deficits were observed in 5 instances. One patient with acute type A dissection died from massive stroke after cardiac arrest and cardiopulmonary resuscitation during induction of anesthesia. Four patients had postoperative hemiparesis after elective cusp (n=2) or root reconstruction (n=2), which subsided within 4 weeks in 2 patients. Thromboembolic events were not noted in the postoperative follow-up. A single case of endocarditis was observed 4.5 years postoperatively for a linearized rate of 0.14% per patient year. This patient had initially undergone root replacement with valve reimplantation and was treated by repeat root replacement using a stentless aortic valve. She recovered adequately and is currently well.

### TABLE 2. Operative Data

<table>
<thead>
<tr>
<th></th>
<th>Isolated Aortic Valve Repair</th>
<th>Isolated Aortic Root Repair</th>
<th>Combined Aortic Valve and Root Repair</th>
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<tr>
<td>CPB time, min</td>
<td>70±26</td>
<td>134±45</td>
<td>116±45</td>
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<tr>
<td>Myocardial ischemia time, min</td>
<td>43±16</td>
<td>94±24</td>
<td>86±23</td>
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<td>Circulation. arrest time, min</td>
<td>11±8</td>
<td>17±10</td>
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<td>Aortic Valve Procedure</td>
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<tr>
<td>Plication 1 cusp, n</td>
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<td>—</td>
<td>67</td>
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<tr>
<td>Plication 2 cusps, n</td>
<td>23</td>
<td>—</td>
<td>26</td>
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<tr>
<td>Plication 3 cusps, n</td>
<td>—</td>
<td>—</td>
<td>3</td>
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<td>Pericardial patch, n</td>
<td>16</td>
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<td>Triangular resection, n</td>
<td>15</td>
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<td>Aortic Root Procedure</td>
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<td>Subcommissural plication, n</td>
<td>59</td>
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<td>Supracommissural replacement, n</td>
<td>27</td>
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<td>Remodeling, n</td>
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<td>Reimplantation, n</td>
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<td>Arch Replacement</td>
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<td>Partial, n</td>
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<td>Total, n</td>
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<td>Concomitant Procedures</td>
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<td>CABG, n</td>
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<td>23</td>
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<td>Mitral repair, n</td>
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<tr>
<td>Miscellaneous</td>
<td>10</td>
<td>6</td>
<td>2</td>
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<tr>
<td>Perioperative Mortality, %</td>
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<td></td>
<td></td>
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<tr>
<td>Total</td>
<td>3.6 (3/83)</td>
<td>4.9 (5/103)</td>
<td>3.1 (3/96)</td>
</tr>
<tr>
<td>Elective</td>
<td>3.7 (3/82)</td>
<td>2.7 (2/73)</td>
<td>3.4 (3/87)</td>
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<tr>
<td>Emergency</td>
<td>0 (0/1)</td>
<td>10.0 (3/30)</td>
<td>0 (0/9)</td>
</tr>
<tr>
<td>AR postoperative</td>
<td>0.8±0.7</td>
<td>0.7±0.8</td>
<td>0.7±0.6</td>
</tr>
<tr>
<td>Mean systolic gradient postoperative, mmHg</td>
<td>3.4±0.8</td>
<td>4.1±0.2</td>
<td>4.2±0.4</td>
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</tbody>
</table>
Recurrent aortic regurgitation led to reoperation in 9 instances 2 to 68 months postoperatively (isolated valve repair, n=3; isolated root reconstruction, n=4; combination, n=2). Of these, 4 underwent reoperation within the first 12 postoperative months. One patient required reoperation for endocarditis 45 months after isolated root repair. The causes of failure included recurrent cusp prolapse (n=4), progressive dilatation of the AV junction (n=2), and cusp retraction (n=2). Actuarial freedom from reoperation after 5 years was 95% (isolated valve repair, n=93%; isolated root reconstruction, n=95%; combination, n=98%) (Figure 8). Most patients have had stable valve function, as documented by transthoracic echocardiography at a mean follow-up of 33±24 months (cumulative follow-up 8425 patient-months, follow-up 99.6% complete). Aortic regurgitation was reduced from 2.7±0.6 to 0.7±0.5 (isolated valve repair 2.8±0.7 to 0.8±0.7, isolated root reconstruction 2.5±0.8 to 0.7±0.8, combination 2.6±0.9 to 0.7±0.6; Tables 1 and 2). Actuarial freedom from AR grade ≥II after 5 years (Figure 7) was 88% (isolated valve repair 81%, isolated root reconstruction 85%, combination 94%). Mean systolic gradient was 3.8±0.4 mmHg (isolated valve repair 3.4±0.8 mmHg, isolated root reconstruction 4.1±0.2 mmHg, combination 4.2±0.4 mmHg).

**Discussion**

Aortic valve replacement has become the standard therapy for advanced aortic stenosis and regurgitation with defined prognostic indicators for surgical treatment.19 The operative risk is low and depends more on the risk profile of the patient than the procedure or the type of implant.23,24 Of the different aortic valve substitutes, all have their respective advantages and disadvantages, particularly the most commonly used mechanical prostheses and xenograft implants.23,24 Although “good” long-term results have often been reported, the risks of thromboembolism, valve thrombosis, anticoagulation-related hemorrhage, and prosthetic valve endocarditis remain long-term.16 The linearized rates of these complications are low; nevertheless, recent reports focusing on mitral valve surgery indicate that valve replacement is associated with long-term survival inferior to predicted levels, whereas mitral repair improves survival to predicted levels.25–28 For the mitral valve, it is thus accepted that repair reduces valve-related morbidity and mortality, whereas there are no comparable data available at this time for aortic valve reconstruction.

Although the first aortic valve reconstructions were already performed in the 1960s, reconstruction did not gain wider acceptance by cardiac surgeons until the 1990s.6,11,14 The reason for this may be related to the fact that any repair procedure on the tricuspid valve with the complex interference of 3 coaptation lines is more difficult compared with a bileaflet (mitral) or bicuspid (aortic) valve.1 For many years, there was uncertainty regarding the prognostic implications of a bicuspid aortic valve—the second most frequent cause of pure regurgitation—and we know by now that the bicuspid valve can function adequately into the seventh decade of life if it has not developed stenosis by the third or fourth decade.31,32 Consequently, good results have been reported for reconstruction of bicuspid aortic valves by some groups.6,9,10

Root dilatation has been increasingly recognized as the most common cause of pure aortic regurgitation.2–4 Two different procedures have been developed in the context of valve-preserving surgery to correct this mechanism. Sarsam and Yacoub7 propagated remodeling of the aortic root to achieve coaptation by reduction of the ST junction. This technique appreciates anatomy and function of the sinuses of Valsalva, which are attributed to physiological aortic valve function and dynamics.33,34 Root stabilization is achieved at the level of the ST junction, leaving the possibility of potential secondary dilatation at the AV junction, which apparently plays a role particularly in patients with Marfan syndrome. A more aggressive approach has been introduced by David et al8 in the form of root replacement with anchoring a vascular graft to the AV junction and reimplantation of the valve inside the Dacron graft. We have used both techniques according to their differences in function and stability for different indications. Root remodeling was used in moderate root dilatation (ST diameter >35 mm), whereas reimplantation was used in patients with severe root dilatation (AV diameter >30 mm). In patients with connective tissue disease, the more radical root procedure, ie, reimplantation, was performed irrespective of AV dimensions.35

In the presence of a normal root size, aortic valve repair is considered by only a minority of surgeons. Different techniques have been proposed with different results.1,6,9–14 Haydar et al1 and Cosgrove and the Cleveland Clinic group6,9,10 found that bicuspid valve anatomy appears to facilitate leaflet reconstruction,6,9,10 because only a single coaptation line has to be appreciated. Others have published suboptimal midterm results after repair of bicuspid valves.36,37 Experience in the repair of tricuspid aortic valves has been published by Rao.38
This experience with aortic valve repair primarily deals with series in which mostly 1 technique was applied for a single pathologic substrate, eg, cusp extension for retraction or cusp plication for prolapse. Freedom from reoperation has not always been >90% at 5 years, and the reasons of failure are not clear from the reports. In only 1 report, secondary root dilatation after cusp repair was identified as cause of secondary valve failure.

It has only relatively recently been recognized that cusp pathology and root dilatation are separate mechanisms involved in the mechanism of aortic regurgitation. These may well coexist, such as in bicuspid aortic valve anatomy, in which >50% of individuals also exhibit signs of aortic wall abnormality. The coexistence of the different mechanisms may have been underestimated, and the limited long-term durability of valve repair procedures in some series may be related to the fact that a less pronounced degree of aortic root dilatation remained uncorrected.

Cusp prolapse not only may coexist with root dilatation but also may be initiated or aggravated by surgical normalization of proximal aortic dilatation. For this situation, we have previously reported that the combination of root and cusp repair is technically feasible and reproducible without increasing operative risk. It expands the potential application of repair procedures in aortic regurgitation (70% in the past 2 years of our experience), and possibly improves long-term stability over isolated root procedures. We have been able to demonstrate encouraging medium-term data for this new provocative approach of valve-sparing aortic replacement in bicuspid and tricuspid anatomy without "pushing the limits." We feel that additional cusp repair has actually strengthened our approach, which is in contrast to the observations by the group from the Mayo Clinic, who identified the necessity of cusp repair as the strongest predictor for failure in valve-preserving aortic surgery by univariate analysis.

Successful repair of AR avoiding prosthetic valve-related morbidity can only be considered successful if this approach carries a reasonable durability similar to prosthetic valves. The standard aortic valve replacement or composite valve graft will thus remain the gold standard for surgical treatment of AR. Nevertheless, the experience with mitral reconstruction demonstrates that a repair with a freedom from reoperation of 95% at 5 years can be superior to replacement despite the somewhat higher risk of reoperation. With the current results, we have been able to achieve valve stability that is comparable to that of mitral reconstruction. It is noteworthy that the risk of endocarditis in the current series is lower than that known for prosthetic endocarditis. If further data confirm this trend, the reduction in the likelihood of postoperative endocarditis may become an argument in favor of repair.

It may be questioned whether it is reasonable to expose the patient to the risk of reoperation of a reconstructed aortic valve when replacement has become rather safe and reproducible. This may apply to the patient older than 65 to 70 years, in whom the durability of current bioprosthetic valves are good and the risks of valve thrombosis, thromboembolism, and coumadin-related hemorrhage are acceptable. At this time, aortic valve reconstruction definitely appears as the better option for patients younger than age 50, in whom bioprosthesis has insufficient durability. Although the risks of thromboembolism and bleeding in the presence of mechanical valves are low in these patients, their long life expectancy will increase the cumulative risk of valve-related morbidity. Although progressive stenosis has been observed in bicuspid aortic valves, this has not occurred in those with pure regurgitation. We have even seen patients with well-preserved pliable cusp morphology in bicuspid anatomy up to the age of 70 years, and we found postoperative systolic gradients in our patients being within physiological range comparable to those of a stentless biological valve, but below the gradients of stented xenograft.

We have not attempted to judge the relative advantages or disadvantages of different techniques in root or cusp repair. Based on the published evidence and our own data, root remodeling and valve reimplantation are root repair procedures with good mid-term valve stability in most patients. In patients with connective tissue disease, valve reimplantation appears to have some advantage in aortic valve durability. For repair of cusp prolapse, we have avoided triangular resection, which has been identified as a risk factor for reoperation. Initially we used plication sutures on the cusp margin close to the commissures, as initially described by Starr and Trusler. After rupture leading to reoperation, we have mainly performed cusp plication in the central portion of the free margin, which is in a low-stress area of the margin.

We thus conclude that reconstruction of aortic regurgitation with a differentiated strategy reproducibly results in encouraging mid-term durability. Prosthetic valve-related complications including endocarditis, thromboembolism, and anticoagulation can be minimized and patients' quality of life improved. Further studies will be required to evaluate long-term durability.

References


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