Results of Aortic Valve-Sparing and Restoration With Autologous Pericardial Leaflet Extensions in Congenital Heart Disease

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Background. **The purpose of this study is to evaluate the efficacy of aortic valve-sparing repair with glutaraldehyde-treated autologous pericardium in congenital valvular pathology.**

Methods. **Sixty-two patients underwent reparative aortic valve surgery from January 1997 through December 2003. The mean age was 25 ± 20 years (± standard deviation) (range, 10 days to 81 years). Fifty percent (31 of 62) were less than 19 years old at operation. The diagnoses included bicuspid aortic valve (39 patients), ventricular septal defect (14 patients), severe aortic stenosis (6 patients), subaortic stenosis (7 patients), bacterial endocarditis (7 patients), neonatal truncus arteriosus (2 patients), Shone's complex (2 patients), transposition complex (1 patient), double-chambered right ventricle (1 patient), and Marfan's syndrome (1 patient). Twelve patients (19 %) had prior sternotomy and cardiac operations. Valve-sparing techniques included pericardial leaflet extensions in 62 patients, creation of one or more pericardial neoaortic sinuses in 8, subcommissuroplasty in 8, pericardial patch of perforated leaflets in 9, Dacron mesh wrap (Boston Scientific, Wayne, NJ) of dilated ascending aorta in 12, and concomitant tricuspid and mitral valve repairs in 3 and 4 patients, respectively.**

Results. **There was one early death (1.6%). There were no late deaths at a mean follow-up of 25 ± 16 (range, 0.1 to 72.5 months). Six patients required reoperation and prosthetic or homograft replacement for aortic valve incompetence. One out of 6 reoperations required re-repair. The remaining patients are well with a mean aortic regurgitation grade by echocardiography of 1.3 ± 0.9 (scale, 0 to 4).**

Conclusions. **Aortic valve repair with pericardial leaflet extension is a promising technique for the growing child.**

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Native aortic valve repair in children and adults with congenital valvular pathology is undergoing resurgence as the growing number of mechanical and biological substitutes reflects no consensus over an optimal therapeutic solution [1–13]. Furthermore, enthusiasm for the Ross pulmonary autograft operation is undergoing reconsideration by some centers as longer follow-up unveil potential double semilunar valve disease; neoaortic insufficiency, future right ventricular outflow tract homograft reintervention, and risks of aortic root reoperation [14–16].

Promising early and mid-term results using glutaraldehyde-treated autologous pericardium for leaflet or cusp extension are emerging [2, 3, 9, 10, 17–22]. This report reviews our initial experience with glutaraldehyde-preserved autologous pericardial leaflet extension for repairing congenital aortic valve pathology. We also review the outcome of restoring the natural tricuspid configuration of the failing congenitally bicuspid valve.

Patients and Methods

This study reviewed hospital medical records, operative notes, echocardiograms and cardiac catheterization data, and outpatient records in all patients undergoing aortic valve repair with pericardial leaflet extension as a central feature. From January 1997 through December 2003, 62 patients underwent aortic valve repair and root remodeling with free-hand autologous pericardium. Twenty four percent (15 of 62) of these patients were females. The mean age for the group was 25.5 years (range, 10 days to 81 years). Fifty percent (31 of 62) of these patients were 18 years of age or younger. Ninety-four percent (58 of 62) of these patients had a diagnosis of congenital heart disease including 31 (50%) with a bicuspid aortic valve. There was no rheumatic heart disease in this cohort. Seven patients (11%) presented with a history of infectious endocarditis, and a single patient had Marfan's syndrome. Twelve patients (19%) had a prior sternotomy for a previous cardiac operation. Four patients (6%) underwent previous thoracotomy for coarctation repair. Six

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Table 1. Previous Surgical Procedures

Procedure	Number of Patients
Ventricular septal defect closure	5
Resection subaortic stenosis	4
Modified Konno	1
Open aortic valvotomy	1
Percutaneous balloon aortic valvuloplasty	6
Aortic coarctation repair	6
Open pulmonary valvotomy	1
Ross procedure	1
Double chamber RV repair	1
Truncus arteriosus repair	1
PDA ligation	2
Pulmonary valve replacement	1
Atrial septal defect closure	1
Bidirectional Glenn shunt	1

RV = right ventricle; PDA = patent ductus arteriosus

patients had remote or prior balloon aortic valvuloplasty before undergoing surgical repair. See Table 1 for other previous cardiac procedures undergone by the patients. During the study time frame other valve substitutes were used for aortic valve replacement at our institution. The decision and choice of reparative technique with autologous pericardium was confined to the practice of one surgeon in our group after an informed consent process with the patient or the family, or both, who ultimately decided in favor of aortic valve repair. Very few patients (< 19 years of age) underwent primary prosthetic aortic valve replacement in this practice during the study period.

The operation was performed with single aortic and bicaval hypothermic cardiopulmonary bypass. The left ventricle was decompressed by venting through the right superior pulmonary vein. Myocardial protection was accomplished with antegrade cold blood cardioplegia (initially through the root and then by direct coronary artery infusion) and retrograde cold blood cardioplegia. After standard median sternotomy the pericardium was exposed and cleaned of fibroareolar tissue and adhesions using sharp and blunt dissection. A sufficient amount of pericardium was harvested from under the sternum. The portion used for aortic valvuloplasty was further stripped of fibroareolar tissue using saline-soaked gauze and was placed in a pH-balanced glutaraldehyde solution for 9 minutes. The glutaraldehyde solution for clinical use is locally prepared by the University of California, Los Angeles Medical Center pharmaceutical technology laboratory under aseptic conditions by ultrafiltration and is tested for sterility by culturing before use. The preparation constitutes a sterile glutaraldehyde 0.625% with a phosphate buffer (pH 7.4) and fluorescein 0.02% formulation. After this tanning process the pericardium was rinsed in three sterile normal saline baths for 2 minutes each prior to creation of the leaflets. The pericardial patches were shaped in appropriate fashion so that the width of each of these patches was 15% greater than the diameter of the aorta. The 15% additional length accounts for a reduction in the pericardial leaflet free edge width from a purse stringing effect with a running polypropylene suture. The height of the pericardial leaflet was measured to bring the extensions just below the sinotubular junction where all extended cusps may naturally coapt in the center of the aorta.

Table 2. Aortic Valve and Root Repair Techniques

Aortoplasty with Dacron mesh wrap	19% (12/62)
Subcommissuroplasty	13% (8/62)
Trileaflet restoration	55% (34/62)
Pericardial patch leaflet	15% (9/62)
Pericardial neo-aortic sinus	13% (8/62)
Pericardial leaflet extension	100% (62/62)

A number of standard reparative techniques were used in this series featuring autologous pericardial leaflet extensions as the hallmark (see Table 2). The leaflet extensions were sutured to the free edges of the residual native leaflets with a running suture of polypropylene. Native leaflets exhibiting excessive fibrosis, thickening, and restriction were trimmed and thinned out to healthy tissue prior to extension with autologous pericardium. The extensions were also attached to the aortic wall creating neocommissures just below the sinotubular junction. Apposition in the center and adequate coaption surface was assessed and imperfections were corrected. The leaflets were anchored by full-thickness suture bites passing through the aorta wall and tied on the outside over a pericardial buttress (Fig 1). As our experience matured, every attempt was made to convert the congenitally bicuspid valve to a natural trileaflet configuration using autologous pericardial leaflet extensions (Figs 1, 2).

Prior to closing, the aortic root leaflet coaptation was evaluated for adequate surface of central leaflet coaption. Excessive pericardial extensions could be trimmed appropriately at this juncture. The root was closed with a running polypropylene suture over a strip of pericardium. In dilated roots, a tailoring aortoplasty may be achieved by excising a portion of the aortic wall prior to closure and circumferentially wrapping the ascending aorta for further reduction and support to reduce wall tension (Fig 1). Conversely, in hypoplastic roots and ascending aortic segments it is important to augment the ascending aorta with pericardium prior to closure to avoid residual gradients. After aortic root closure, the pressure generated during final infusion of warm blood antegrade cardioplegia at physiologic calculated coronary flow rates provided a reasonable estimate of valve competency prior to removal of the aortic cross clamp. Finally after separation from cardiopulmonary bypass, intraoperative transesophageal echocardiography was used to assess aortic root anatomy and function.

Combined procedures included tricuspid valve repairs in

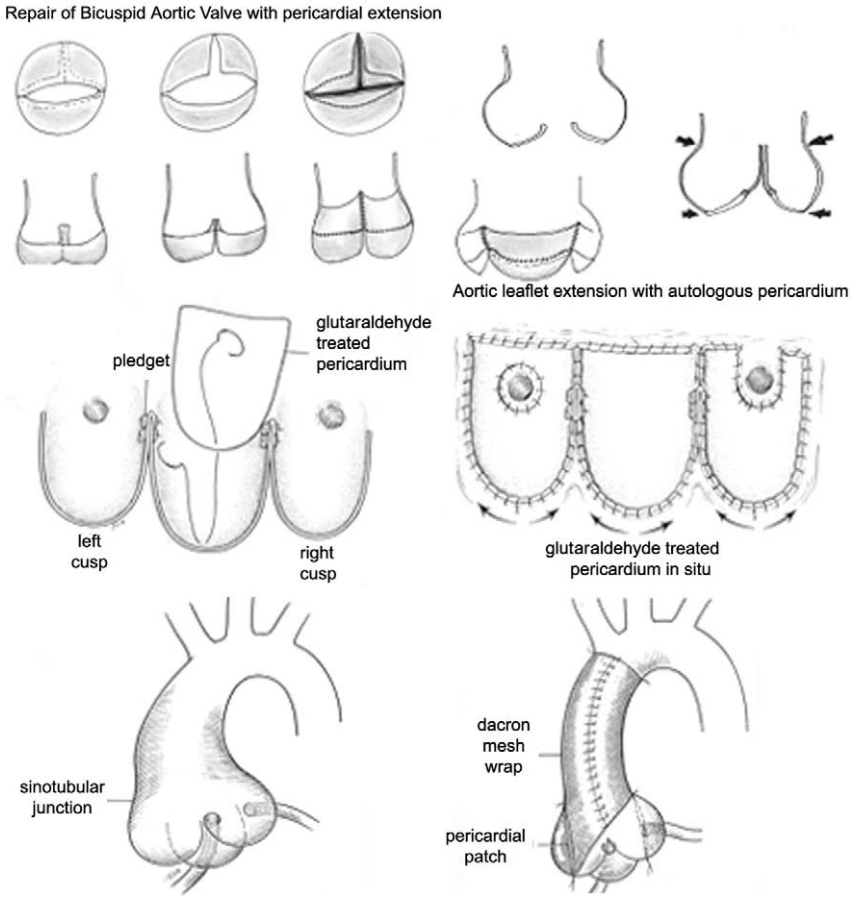

*Fig 1. Conversion of bicuspid aortic valve to tricuspid configuration and cusp augmentation with autologous pericardial leaflet extensions. The median raphe of the conjoined cusp is incised from the free edge up to the annulus. The fibrotic, stiff, and rolled-up free edges are thinned back to pliable tissue. Glutaraldehyde-treated autologous pericardial extensions are sewn to the native free-edges with a running polypropylene suture up to the aortic wall. The suture line is continued up the aortic wall (full thickness) to just below the sinotubular junction. The pericardial leaflet extensions are secured to one another over a pericardial pledget on the outside of the aorta. This creates neo-commissures just below the sinotubular junction (*bold arrows at top*) and a taller interleaflet triangle creating optimal zone of coaptation. The hinge point of the valve (*arrows below*) remains in the pliable native cusp remnant ensuring flexibility and valve function in the event of leaflet extension fibrosis or calcification. Dilated and aneurysmal sinuses of valsalva are excluded from the remodeled aortic root with glutaraldehyde-treated pericardial lining. It is typical for relative dilation of the noncoronary sinus; however with connective tissue disorders all three sinuses may be involved and are excluded with pericardial lining to prevent further dilation, rupture, or dissection. Sinuses harboring coronary arteries require pericardial button removal overlying the ostia.*

8% (5 of 62), mitral valve repairs in 11% (7 of 62), pulmonary valve replacement in 1, and coronary revascularization in 2 older patients (Table 3). The other non-aortic valvular repairs were annuloplasties performed with a strip of glutaraldehyde-treated pericardium.

Follow-Up

Follow-up was conducted over the last 6 months and was 100% complete. The follow-up echocardiographic data and medical conditions were obtained from records of the referring cardiologists. The mean follow-up period was 25 ± 16.9 months postoperatively (range, 0.1 to 72.5 postoperative months). Patients were not anti-coagulated for aortic valve repair but were placed on antiplatelet agents.

The primary end points of this retrospective study were early and late mortality, freedom from reoperation and late valve function. The study was approved by the Institutional Review Board at the University of California, Los Angeles Medical Center.

Results

No patient left the operating room with an aortic regurgitation (AR) grade of 2 or greater. Forty-five patients (70%) and 18 patients (28%) had a grade of zero or 1, respectively. Two patients required reinstitution of cardiopulmonary bypass for an unsatisfactory repair. In one instance, a 2½-year-old boy with critical bicuspid aortic stenosis underwent reversion to a trileaflet valve with pericardial leaflet extensions. He had an unacceptable residual gradient and required additional pericardial augmentation to enlarge the aorta from the level of the annulus to the mid-ascending aorta to reduce leaflet crowding at the sinotubular junction. In another patient myocardial ischemia was reversed by trimming an excessive pericardial leaflet extension.

There was 1 early mortality and no late mortalities. The mortal event occurred in a 2½-year-old boy with critical aortic stenosis and a bicuspid aortic valve. The peak and mean preoperative gradients on echocardiography were 89 and 36 mm Hg, respectively, with left ventricular hypertrophy and a left ventricular ejection fraction of 64%. At the time of operation there was fusion of the left and right cusps. The noncoronary cusp was large and pliable. The thickening of the free edges of both conjoined and noncoronary leaflet were resected and thinned. The rudimentary median raphe was incised out to the annulus creating a trileaflet valve. The noncoronary leaflet was suspended at a higher level with a

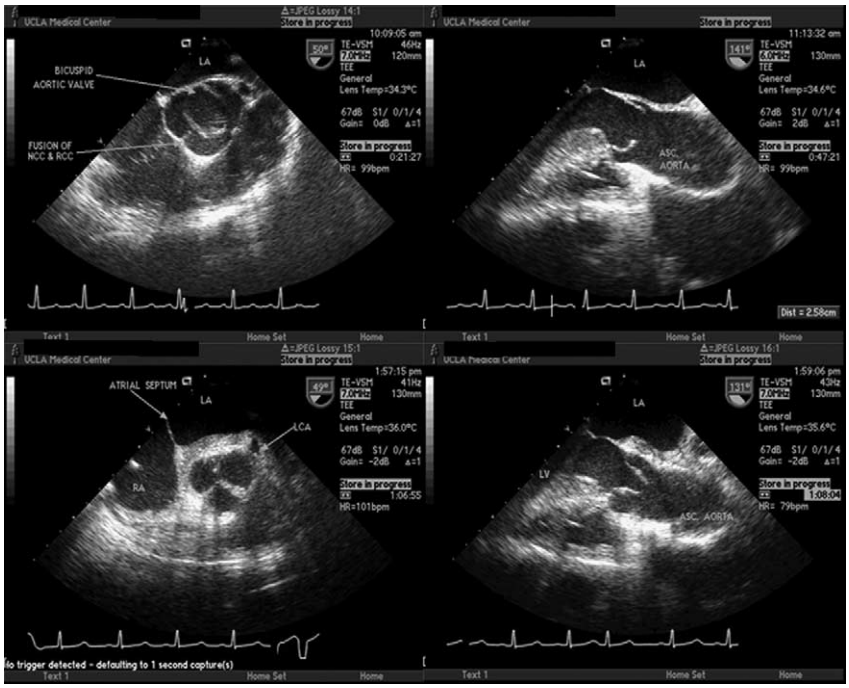

Fig 2. Fusion of noncoronary and right coronary cusps to form conjoined leaflet with doming of the bicuspid aortic valve (upper panel). Trileaflet valve conversion with autologous pericardial leaflet extensions with classic "Mercedes Benz" sign in cross-section and resolution of valve doming (lower panel). (ASC. AORTA = *ascending aorta;* LA = *left atrium;* LCA = *left coronary artery;* LV = *left ventricle;* RA = *right atrium.*)

horizontal mattress suture of 4-0 polypropylene with pericardial pledgets. The left and right coronary cusps were extended 3 to 4 mm with glutaraldehyde-treated autologous pericardium. To reduce potential crowding at the sinotubular junction, another glutaraldehyde-treated pericardial patch was used to enlarge the ascending aorta from the level of the annulus. The patient separated smoothly from cardiopulmonary bypass and the post repair intraoperative transesophageal echocardiography confirmed a competent aortic valve. The patient was extubated on the day of surgery. A postoperative two-dimensional echocardiography and Doppler study demonstrated a tricuspid aortic valve with minimal AR and mild stenosis. The peak and mean aortic gradients were 28 and 15 mm Hg, respectively. On the evening of this patient's discharge (postoperative day 4) he aspirated during feeding and suffered a cardiopulmonary arrest. He was resuscitated and placed on extracorporeal membrane oxygenation. He succumbed to severe anoxic brain injury and multiorgan failure. A postmortem examination confirmed intact reconstruction of the aortic valve, diffuse cerebral edema, and multiorgan ischemia.

Reoperations

There were six reoperations for valve-related conditions with a mean of 17 ± 17.2 months (range, 0.1 to 42.5 months). The mechanism was related to infectious endocarditis in 3 adult patients in their 30s with bicuspid native aortic valves prompting replacement in 2 patients with aortic allograft and bioprosthetic valves and re-repair in one. Another patient who had congenital dwarfism and an osteolytic syndrome affecting connective tissue, cartilage, and bone suffered from panvalvular disease. She required mechanical valve replacement 3 years later after accelerated failure of aortic valve repair with pericardial leaflet extensions. She also needed mechanical valve replacement in the mitral, tricuspid, and pulmonary positions. A fifth patient in his late 20s had a prior history of resection of subaortic stenosis. He underwent aortic valve repair for a stenotic bicuspid aortic valve with a pericardial leaflet extension after re-resection of the subaortic area. He separated from cardiopulmonary bypass uneventfully with excellent hemodynamics and good valve performance, although he suffered a fibrillatory arrest during closure. He was put back on cardiopulmonary bypass for resuscitation and subsequently underwent a modified Konno operation with takedown of the repair in favor of an aortic bioprosthesis. The cause of the ventricular fibrillation was likely due to coronary air embolism. A final, sixth patient in his 30s had severe AR develop a few months after aortic valve repair of a bicuspid leaking valve with pericardial leaflet extensions of the right and left coronary formerly conjoined cusps. He underwent aortic valve replacement with a mechanical device after finding a torn noncoronary cusp and right and left coronary cusps with intact pericardial leaflet extensions. In retrospect, we may have erred in not supporting the noncoronary cusp with a leaflet extension.

Table 3. Concomitant Surgical Procedures with Aortic Valve Repair

Mitral valve repair	11% (7/62)
Tricuspid valve repair	8% (5/62)
Pulmonary valve replacement	2% (1/62)
Coronary artery bypass grafting	3% (2/62)

The 2-year freedom from valve-related reoperation for

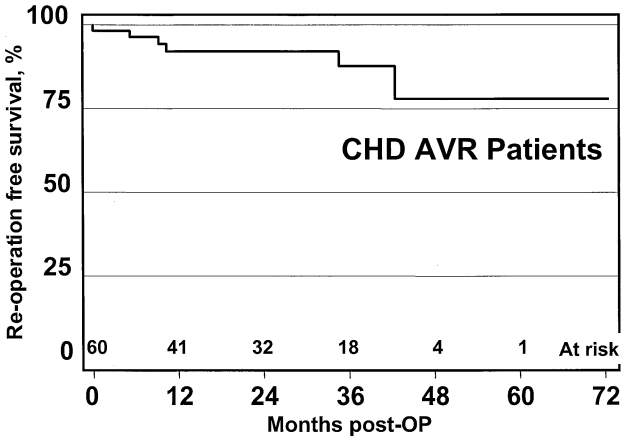

Fig 3. Freedom from valve-related reoperation. (AVR = *aortic valve repair;* CHD = *congenital heart disease;* post-OP = *postoperative.*)

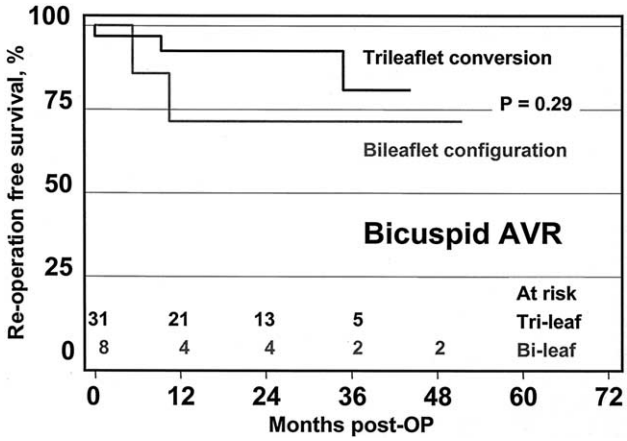

Fig 5. Impact or restoration of trileaflet semilunar configuration. (AVR = *aortic valve repair;* post-OP = *postoperative.*)

patients with congenital heart disease was 92% (Fig 3). For pediatric patients ≤ 18 years of age this freedom from valve-related reoperation was 100% at 2 years (Fig 4). Aortic valve repair with pericardial leaflet extensions in the pediatric group has a higher freedom from valve-related reoperations than adults after a mean follow-up of 2 years. Complications due to infectious endocarditis played an insignificant role in the pediatric population in contrast with adults.

There were five non-valve related reoperations at a mean of 8 ± 13.4 months (range, 0.1 to 33 months). Three patients required return to the operating room for postoperative bleeding. Two other patients returned to surgery for wound debridement of sternal infections; one of the patients was a 10 day-old neonate with truncus arteriosus undergoing truncal valve repair with leaflet extensions and delayed sternal closure, the other was a redo sternotomy for previous aortic and mitral valve surgery. These associated conditions may have predisposed the latter 2 patients to sternal wound problems.

There were no instances of valve thrombosis, thromboembolism, neurologic events, or renal failure in this group. A 10-month-old infant with a history of a modified Konno procedure and subaortic resection for subaortic and aortic stenosis, aortic coarctation repair, and residual ventricular septal defect underwent aortic and mitral valve repair, re-resection of the subaortic area, and ventricular septal defect closure at our institution and experienced postoperative heart block requiring permanent pacing. A 56-year-old man undergoing aortic valve repair for a leaky bicuspid valve with dilation of the ascending aorta through a right mini-thoracotomy had a flail chest from costochrondral separation develop.

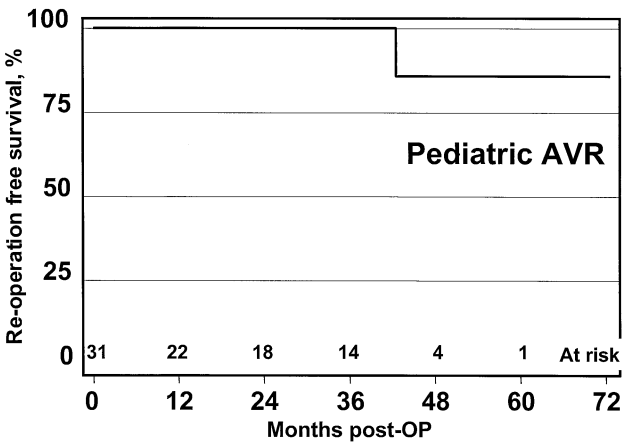

Fig 4. Freedom from valve-related reoperation after repair (age, < 19 years). (AVR = *aortic valve repair,* post-OP = *postoperative.*)

Restoration of Trileaflet Configuration in Bicuspid Valves

Thirty-nine patients (63%) had congenitally bicuspid valves with a conjoined leaflet, which was usually the product of fusion between the right and left coronary cusps or some other combination. Thirty-four patients (87%) were successfully converted to trileaflet valves with the use of autologous pericardial extensions (Figs 1, 2). The 2-year freedom from reoperation after trileaflet conversion was 90%, whereas those patients with pericardial leaflet extensions of the bicuspid valves had a lower 2-year freedom from reoperation at 70% (Fig 5). This trend was not statistically important ($p = 0.29$).

Valve Function

The preoperative AR grade was a mean of 3.3 ± 1 with 75% of the patients presenting with severity grades of 3 and 4. The mean severity grade of post-repair intraoperative AR was 0.3. The preoperative aortic stenosis (AS) grade was a mean of 0.7 ± 1.3 with 88% of the study group having no or mild aortic stenosis. One patient had an aortic stenosis severity grade by Doppler echocardiography of 2, 2 patients had a grade of 3, and 6 patients had a grade of 4. At late follow-up, 60% of all patients had no AR or only a trace (ie, grades 0 and 1). Twenty patients (32%) had mild AR and 4 patients (6%) had moderate AR. Seventy-percent of patients had no aortic stenosis or only

a trace. Thirteen patients had mild stenosis and 1 had moderate stenosis.

Comment

The ideal valve substitute or reparative technique for congenital aortic valve pathology remains illusive despite progress and refinements in mechanical and bioprosthetic valves, allograft biology, and Ross's introduction of the pulmonary autograft. The biologic constraints of growing children, pregnancy, tissue antigenicity, calcium metabolism, and synthetic valve substitutes herald bleeding and thromboembolic complications, prosthesis–patient mismatch, calcification, and degeneration, and double semilunar valve disease, thereby impacting long-term durability. Furthermore the economics of valvular disease management make current surgical options out of reach for the majority of the globe. Aortic valve repair is a slowly evolving option initially pioneered in developing areas of the world where compliance and anticoagulation management have hampered widespread adoption of replacement substitutes and long-term durability [1–3, 20, 22]. The pulmonary autograft is an attractive alternative, but as a long-term follow-up accrues, an increasing awareness of inherent structural wall abnormalities in the pulmonary trunk predisposing to neoaortic dilation and increased autograft failure rate [13, 19] has prompted some groups to revisit aortic valve repair with leaflet extension [20, 22].

The appropriate material for aortic cusp extension remains elusive, although fresh autologous pericardium and bovine pericardium were historically limited by short-term durability [1, 4, 9, 10]. Treatment of autologous pericardium with glutaraldehyde seems to improve durability of these repairs, but for how long remains unknown, although anecdotal evidence points to a 6-year to 8-year limit before an increased hazard for degeneration [7]. Al Fagin and colleagues [1] reported on a series of 20 young adults undergoing aortic valve repair for rheumatic pathology with cusp extension using bovine pericardium. They reported significant improvements in signs and symptoms with good relief of stenosis and regurgitation at a mean of 7 ½ months and at the longest follow-up of 23 months. Duran and colleagues [2, 3, 9, 10] demonstrated improved performance with autologous rather than heterologous bovine pericardial material for cusp extension. In 27 and 64 patients undergoing aortic valve reconstruction with bovine and autologous pericardium, respectively, the actuarial survival and freedom from structural deterioration at 8 years were 82 ± 10 % and 76 ± 11 % for bovine and 91 ± 4 % and 97 ± 2 % for autologous pericardium, respectively [9]. In theory, absent antigenicity with autologous pericardium should confer greater resistance to degeneration than heterologous pericardium independent of treatment with a tanning or fixative agent. The parallel experience of increasing device survival with glutaraldehyde tanning of bioprosthetic valves has resulted in similar treatment of fresh autologous pericardial leaflet extensions because fresh autologous pericardium was associated with poorer results due to early thickening and retraction. Glutaraldehyde treatment endows the pericardium with more resistance to retraction and degeneration, and increases the ease of handling while retaining intrinsic tissue pliability. The effects on long-term calcification and on induction of immunologic responses consistent with host versus graft reaction remain unknown [7].

More recent reports of aortic valve repair with pericardial leaflet extensions show evolving promise. Bozbuga and colleagues [22] reported on 46 patients (mean age, 32 years), who were mostly adults with rheumatic disease undergoing pericardial cusp extensions. Actuarial survival was 98 ± 2 % at 8.6 years. However, disturbingly, the reoperation rate was 20% (4.3% per patient-year) due to significant progression of rheumatic disease with dense fibrosis. The mean interval between repair and reoperation was 28 ±18 months (range, 3 to 58 months). Grinda and coworkers [20] studied aortic valve repair in 89 patients with half the mean age (mean age, 16 ± 5 years) also afflicted with rheumatic disease. The actuarial survival at 5 years was 96%, and 92% were free of redo valvular surgery. At 7 years, 90% of patients were free of valve-related complications. These results, in a much younger population with rheumatic aortic valve pathology, suggest better early and mid-term outcomes with glutaraldehyde-treated autologous pericardial leaflet extensions. The finding of improved freedom from reoperation in younger ages is consistent with the present study findings. Rheumatic valvular pathology may negatively impact the durability of this method of aortic valve repair.

Successful aortic valve repair demands an understanding of anatomy and pathology of the aortic root and requires surgical techniques to address pathology at multiple levels. Subaortic stenosis requires resection. A dilated or restricted aortic annulus will require subcommisuroplasty or an anterior or posterior enlargement. Pathology of the semilunar cusps may manifest with thickening, calcification, retraction, or prolapse that requires leaflet thinning and shaving, leaflet extensions with pericardium or leaflet re-suspension. Leaflet perforations are managed with patches of pericardium. Dilated and aneurysmal sinuses, most commonly the noncoronary, may require exclusion with a pericardial patch (neo-sinus). A dilated sinotubular junction or an ascending aorta, or both, may require plication, aortic wrapping, or resection.

Our experience indicates that the best results are obtained when sufficient native aortic tissue including the hinge point of the native leaflet remains prior to leaflet extension. When possible, repair of congenitally bicuspid aortic valves by tricuspid conversion confers better outcomes, although this did not reach statistical significance in this analysis probably due to insufficient sample size.

The study limitations in this non-random and retrospective study involved 62 patients with heterogeneous valvular pathology, although a congenitally bicuspid valve was featured in more than half the cohort. The mechanisms for AR or stenosis, or both, were similarly heterogeneous related to

underlying congenital heart pathology, previous surgical interventions, or percutaneous interventions, or a combination thereof. The surgical repair of the aortic valve (more appropriately, the aortic root or apparatus as in mitral valve disease) was varied with the common denominator in all cases (ie, leaflet extensions with glutaraldehyde preserved autologous pericardium of one, two, or three cusps). In most instances we succeeded in converting the bicuspid aortic valve to a trileaflet valve with division along the median raphe and pericardial leaflet extensions. Additional root procedures to address dilated sinuses of valsalva, annulus, and ascending aorta were necessary in many instances. Thus, the relatively small numbers and confounders make subgroup analysis inherently difficult in comparison with other published series.

In conclusion this study demonstrates that aortic valve repair with autologous leaflet extension is safe and effective in the short and intermediate term for patients with congenital aortic pathology. The mortality and morbidity for this operation is very low. This observation complements the body of literature demonstrating similar results in populations with predominant rheumatic valvular disease. The congenitally bicuspid valve is reliably restored to normal trileaflet configuration with pericardial leaflet extensions in most instances. The trend in this study toward improved freedom from reoperation suggests improved durability of this trileaflet configuration over the repaired bicuspid valve. The potential mechanism for this is unknown, but it may relate to reduction in leaflet stress load and improved flow patterns. At the very least this technique in the intermediate run may spare the growing child the potentially significant complications from alternative strategies (pulmonary autograft, prosthetic valve, and allograft) until a much later and mature date. Aortic reparative techniques will continue to evolve in light of favorable intermediate-term outcomes.

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DISCUSSION

DR KIRK R. KANTER (Atlanta, GA): Jonah, the question that all of us, I'm sure, are thinking is what constitutes a valve that cannot be repaired? What bicuspid aortic valve is not suitable for this technique and therefore has to undergo a Ross procedure or another valve replacement?

DR ODIM: Thank you, Dr Kanter. Clearly, if you have disease that has destroyed the aortic root and leaflet tissue that is one setting in which it would be very difficult, at least with present techniques, to repair. Bicuspid aortic valve pathology in the much older patient presents this way in the 6th, 7th, and 8th decades of life, where you have extraordinary amounts of annular and leaflet calcification that make reconstruction very difficult.

DR DOMINIQUE METRAS (Marseille, France): That was a very interesting and spectacular presentation. In the same period of

time, how many patients did need an aortic valve replacement? Was that a consecutive series of all aortic valve procedures, or in the same time did you have to replace valves in children?

DR ODIM: That's a good question. This is not a consecutive series of all operations on the aortic valve during this period. There were patients that had aortic valve replacements with mechanical and other types of prosthetic substitutes based on discussion of available options between surgeon and patient, and the final choice of the patient following an informed consent process.

This series is essentially a consecutive series from the senior surgeon in our group who tackled valves of this nature using autologous pericardial leaflet extensions. For the most part, if we felt the valve could be repaired preoperatively, it was successfully repaired, based on assessments of the aortic root subaortic region, and ascending aorta.

DR METRAS: In other words, what percentage of aortic valve surgery in children is done with this technique as opposed to aortic valve replacement?

DR ODIM: I would have to say, without knowing that number exactly, the majority of our children are getting this technique.

DR RANDAS BATISTA (Curitiba, Brazil): Dr. Odim, I congratulate you and your group for these results. I have a similar experience. We presented our experience in 1986. At that time we had 60 patients; now we have 900. I don't extend the cusps. I prefer to change the whole valve, not do only extension. Most of the times I find the edge of the leaflet to be quite thin, for that reason I prefer to place the suture right at the annulus. Thank you.

DR ODIM: Thank you very much. We acknowledge your excellent and pioneering work. We find, in many instances, because the pathology is heterogeneous, it is necessary to resect variable amounts of leaflet tissue. And from time to time, we will go to the annulus and reconstruct from that point.

DR HILLEL LAKS (Los Angeles, CA): I just want to mention two cases that Jonah mentioned. There were two neonates who had truncal valve with both regurgitation and stenosis, which were quite severe; four-leaflet valves that would have required a very complex repair or else root replacement. In both of them, they were converted to three-leaflet valves with leaflet extension after debridement of the thickened leaflets and both had completely competent, unobstructed valves at the end. So this is a tremendous part of the armamentarium of the surgeon in this kind of procedure.

And with regard to the limitations, in children, I would say that pretty much every bicuspid valve is amenable to this kind of repair. As Dr Batista mentioned, there are some children who have a connective tissue weakness with a very dilated root and with very thinned-out leaflets, there was no raphe. So it is a truly bicuspid valve with no thickened raphe. And in those, just dividing and then sewing the leaflet extension, we have also been concerned about the possibility of dehiscence. And in some of those, we did two-leaflet repairs.

One of the failures was a patient, who, as Jonah mentioned, we extended only two leaflets, and at that time we suspended the larger leaflet hoping that if we left at least one leaflet without the replacement it would last even longer. And it turned out that this one leaflet re-prolapsed and caused the regurgitation, so we now feel that if you're going to do the extension all three leaflets should be extended.

And the other point that Jonah made already is that you have to anchor them full thickness with the pledget outside the aorta to avoid them cutting through and prolapsing.

And the other issue is that in children who have a hyperplastic ascending aorta with a three-leaflet extension, you end up with quite a mass of tissue near the sinotubular junction. And in order to avoid a gradient, which we had in 2 patients, and once we got about a 20-mm, 30-mm gradient in each of them, we went back and just put a patch on the ascending aorta and the gradient completely disappeared. So in the small aorta we think that you should, as part of your treatment, make the aorta slightly bigger with a patch at the time of the initial repair.

But the beauty of this is that you have a very low-risk procedure and you can put off a Ross, which damages two valves, until a child is in his teens, instead of doing it when he's 3 or 4. And we think that that's one of the major advantages. It doesn't mean you can't do the Ross in the future if this valve deteriorates at that point.