Reconstruction of Bicuspid Aortic Valve With Autologous Pericardium – Usefulness of Tricuspidization –

Shigeyuki Ozaki, MD, PhD; Isamu Kawase, MD, PhD; Hiromasa Yamashita, MD; Shin Uchida, MD;
Yukinari Nozawa, MD; Mikio Takatoh, MD; So Hagiwara, MD; Nagaki Kiyohara, MD

Background: This study describes the surgical treatment of bicuspid aortic valve with original aortic valve reconstruction.

Methods and Results: Aortic valve reconstruction was done in 102 patients with bicuspid aortic valve from April 2007 through September 2011. Thirty-four patients with ascending aortic diameter >45mm underwent hemi-arch aortic replacement concomitantly. Seventy-seven patients had aortic stenosis, and 25 had aortic regurgitation (AR). Mean age was 63.7 ± 10.0 years old. There were 55 men and 47 women. Harvested pericardium is treated with 0.6% glutaraldehyde solution. The distance between commissures is measured with an original sizing instrument. For bicuspid valve with raphe, the raphe is considered as a commissure in order to measure the distance between each commissure. Without a raphe, we create a new annular margin and commissure using coronary ostium and the sizing instrument as a guide. Then, pericardium is trimmed with original template. Three cusps are sutured independently. The preoperative averaged peak pressure gradient of 71.1 ± 39.0 mmHg was decreased to 16.2 ± 8.8 , 13.3 ± 6.0 , and 13.9 ± 5.6 mmHg, respectively 1 week, 1 year, and 3 years after operation. AR was trivial. One reoperation was recorded. Mean follow-up was 733 days. There were 5 late mortalities. No thromboembolic event was recorded.

Conclusions: Medium-term results were excellent. Tricuspidization gave good opening and closure of aortic valve with excellent hemodynamics. (*Circ J* 2014; **78**: 1144–1151)

Key Words: Aortic valve repair; Aortic valve replacement; Heart valve autograft; Pericardium

Bicuspid aortic valve (BAV) is currently the most popular congenital heart anomaly affecting 1–2% of the population, with a male predominance.¹ Leonardo da Vinci sketched aortic valves as early as 1570 with 2, 3, and 4 cusps. He was 1 of the first to call attention to the aortic valve with 2 cusps. He seemed to recognize the superior engineering advantages of the normal tricuspid valve.^{2,3}

Editorial p 1063

Aortic regurgitation (AR) and aortic stenosis (AS) are frequent complications, with the peak incidence of AR at 30 years and AS typically in the seventh decade of life.^{4,5} Also, the proximal aorta is prone to dilate among up to 50–60% of patients with BAV.⁶

The treatment for complicated BAV is primarily surgical. Diverse surgical options exist for patients with BAV, depending on age at presentation and the size and appearance of the aorta.⁷ Aortic valve replacement (AVR) with or without replacement

of proximal aorta is an effective and widely accepted intervention in patients with AR or AS, but both mechanical and bioprosthetic valves have limitations.^{8,9} The Ross procedure is efficacious for young patients, but there is a risk of pulmonary autograft failure.^{10,11} Valve-sparing techniques have excellent results if the native aortic valve is good enough to be preserved. BAV repair techniques include aortic valve tricuspidization, cusp re-suspension, triangular resection, commissural plication, circumferential annuloplasty, pericardial patch repair for cusp perforation, and pericardial extension valvuloplasty.

Getting back to grass roots, we have a high regard for Leonardo da Vinci's insight. We believe in the hemodynamic superiority of a 3-cusp valve. Given that our original aortic valve reconstruction with glutaraldehyde-treated autologous pericardium has been used for various aortic valve diseases, we evaluate the feasibility and efficacy of this procedure as a surgical treatment of BAV.

Received October 31, 2013; revised manuscript received January 7, 2014; accepted January 9, 2014; released online March 7, 2014 Time for primary review: 26 days

Department of Cardiovascular Surgery, Toho University Ohashi Medical Center, Tokyo, Japan

Mailing address: Shigeyuki Ozaki, MD, PhD, Department of Cardiovascular Surgery, Toho University, Ohashi Medical Center, 2-17-6 Ohashi, Meguro, Tokyo 153-8515, Japan. E-mail: ozakis@oha.toho-u.ac.jp

ISSN-1346-9843 doi:10.1253/circj.CJ-13-1335

All rights are reserved to the Japanese Circulation Society. For permissions, please e-mail: cj@j-circ.or.jp

Figure 1. (A) Aortic valve reconstruction of bicuspid aortic valve with raphe. (A-a) Bicuspid valve with raphe; (A-b) measuring the distance between each commissure with the original sizing apparatus using the raphe as a new commissure; (A-c) trimming the treated pericardium with original template of measured size; (A-d) completion of reconstruction with 3 autologous pericardial cusps. (B) Aortic valve reconstruction of bicuspid aortic valve without raphe. (B-a) Bicuspid valve without raphe; (B-b) according to the location of the right coronary ostium (in this case), deciding on the size of the commissure and the point at which the new commissure should be inserted according to the natural curve, using the original sizing apparatus; (B-c) sewing the pericardial cusp along the newly created annular margin to the new commissure; (B-d) completion of reconstruction with 3 autologous pericardial cusps.

Methods

Our new original aortic valve reconstruction (AVRec) and the clinical study of this procedure were approved by the institutional review board of Toho University Ohashi Medical Center. Additionally, all patients had undergone this operation after written informed consent had been obtained.

From April 2007 through September 2011, AVRec was performed for 102 patients with BAV. All 102 consecutive patients were enrolled in this study. Medical records were carefully reviewed retrospectively. The mean age of enrolled 102 patients was 63.7 ± 10.0 years. There were 55 men and 47 women. Seventy-seven patients had AS, and 25 had AR. Thirty-four

patients (32.7%) with ascending aortic diameter >45 mm underwent the ascending and hemi-arch aortic replacement concomitantly for the prevention of future aortic dissection. Other concomitant procedures included 5 coronary artery bypass graft surgeries, 4 Maze procedures, 2 mitral valve repairs, 2 aortic root reimplantations, and combination of several procedures. Isolated aortic valve reconstructions were performed for 49 patients (48.0%) among 102 patients with BAV.

Surgical Technique

Autologous pericardium is harvested after the usual median sternotomy. In most cases, a 7×8 -cm piece of pericardium is sufficient for AVRec. The harvested pericardium is then treated

Figure 2. (Left) The aorta is encircled by a felt strip at the level of the commissure. (Center) This will prevent future dilatation of aorta at the commissure level, which may cause central aortic regurgitation. (Right) In the case of future dilatation of the sinus of Valsalva, the central coapting point of the valve cusps may become lower than the original reconstructed point. But even in this situation, the longer coapting zone designed in this operation may be able to preserve sufficient coaptation during the longer period.

Figure 3. Kaplan-Meier overall survival curve after aortic valve reconstruction. Survival rate was 80.4% at 60 months after surgery.

with a 0.6% glutaraldehyde solution for 10 min. Cardiopulmonary bypass is established with aortic and right atrial cannulations. Venous cannula is a single 2-stage cannula unless a concomitant procedure is needed in the right or left atrium. The heart is arrested in diastole by retrograde and antegrade cold blood cardioplegia. Arrest is maintained by cold blood retrograde cardioplegia every 20–30 min and cold blood antegrade cardioplegia every 1 h.

Transverse aortotomy is done 1.5 cm distal from the right coronary ostium. After resection of the diseased aortic cusps, the distance between each commissure is then measured using a self-developed sizing apparatus. For the BAV with raphe, we consider the raphe as a commissure in order to measure the distance between each commissure. We also create a new commissure at the same height as other commissures along the raphe (Figure 1-A). For patients without raphe, we create a new annular margin line and commissure according to the location of

the coronary ostium using our original sizing apparatus as guide (Figure 1-B). Glutaraldehyde-treated autologous pericardium is trimmed with a self-developed template corresponding to the measured value. The annular margin of the pericardial leaflet is running sutured with 4-0 monofilament sutures to each annulus or the newly created annular margin line. Commissural coaptation was secured with additional 4-0 monofilament sutures. The coaptation of the 3 cusps is then checked with negative pressure on left ventricular vent. After closure of aortotomy and removal of aortic cross clamp, the aorta is encircled by a felt strip at the commissural level. This will prevent future dilatation of the aorta at the commissural level, which may cause the central AR. In the case of future dilatation of the sinus of Valsalva, the central coaptation point of the valve cusps may become lower than the original reconstructed situation. Even in this situation, however, the larger coaptation zone designed in this operation system might be sufficient to prevent future regur-

Figure 4. Kaplan-Meier freedom from reoperation curve after aortic valve reconstruction. Freedom from reoperation rate was 99.0% at 60 months after surgery.

Figure 5. Postoperative echocardiographic follow-up of peak pressure gradient through newly created aortic valve. Echocardiographic evaluation was done 1 week, 1 month, 3 months, and every 6 months after surgery. OPE, operation.

gitation (Figure 2).

The general technique of AVRec has been described in detail in previous reports.^{12–15}

Statistical Analysis

Echocardiographic evaluation was done 1 week, 1 month, 3 months, and every 6 months after surgery. Data are given as mean±SD. Survival rate and freedom from reoperation rate were calculated using the Kaplan-Meier method.

Results

No conversion to conventional prosthetic valve replacement was recorded. Mean aortic cross-clamp time and cardiopulmonary bypass time were 116.6 ± 27.9 min and 153.2 ± 28.9 min, respectively. There was 1 in-hospital death (1.0%) due to pneumonia. Mean follow-up period was 733 days. On Kaplan-Meier analysis, overall survival at 5 years was 80.4% (Figure 3). There were 5 late mortalities. The causes of late death included pneumonia 3 months after surgery; pancreatic cancer in 2 patients

Figure 6. Postoperative echocardiographic follow-up of aortic regurgitation (AR). Echocardiographic evaluation was done 1 week, 1 month, 3 months, and every 6 months after surgery.

Figure 7. Using a circular model of the tricuspid valve, the total free-edge length approximates its circumference length. In the bicuspid valve model, however, the free-edge length of the cusp becomes shorter than the circumference length. In the quadricuspid valve, the free-edge length of the cusp becomes longer than the circumference length. In short, the tricuspid valve is the best for full opening and complete closure in a circular model.

25 months and 51 months after surgery, respectively; renal pelvis cancer 25 months after surgery; and an unknown cause in a patient who participated in a full marathon 24 months after surgery. One reoperation was recorded due to infective endocarditis following permanent pacemaker implantation 10 months after aortic valve reconstruction. Freedom from reoperation rate was 99.0% at 5 years on Kaplan-Meier analysis (Figure 4). The patients were followed up without anticoagulation. Nine patients had taken warfarin after surgery because of concomitant procedures including coronary artery bypass graft, mitral valve repair or replacement. No thromboembolic event was recorded during the follow-up period. On trans-thoracic echo-

cardiography follow-up 3 years after surgery, average peak pressure gradient was maintained at <20 mmHg. On preoperative echocardiography the averaged peak pressure gradient was 71.1 ± 39.0 mmHg. Peak pressure gradient decreased to 16.2 ± 8.8 , 13.3 ± 6.0 , and 13.9 ± 5.6 mmHg, respectively, 1 week, 1 year, and 3 years after operation (Figure 5). Additionally, only trivial AR was recorded after aortic valve reconstruction (Figure 6).

Discussion

The anatomy of BAV is the most common congenital cardiovascular malformation. People with BAV may develop symp-

tomatic AR or AS earlier in life compared to those with tricuspid aortic valve. In addition to the development of aortic valvular disease at a younger age, the presence of bicuspid valve is also associated with diseases of the aorta. Currently, for individuals who develop disease in the BAV or aortic aneurysm, the only available treatment is surgical repair or replacement of the valve and/or aorta. In terms of surgical treatment of AS, which most of the present patients had, elective AVR should be considered

even for octogenarians with AS before progression of left ventricular impairment.¹⁶

In terms of the surgical treatment of aortic valve itself, the methods are replacement and repair. Valve-sparing operations can also be categorized broadly into interventions on the aortic valve itself and those aimed at repairing the proximal aorta.

AVR is now acknowledged as a safe and effective operation for aortic valve disease. The recent large scale study of AVR

with 7,883 Japanese patients from 2005 through 2008 noted an operative mortality of 3%.¹⁷ Conventional AVR presents complications derived from prosthetic valves. Mechanical valves require life-long anticoagulation, and bioprostheses are associated with high rates of degeneration and the need for another revision surgery.^{8,9} Although there have been remarkable advances in prosthetic valve technology and anticoagulant therapy, prosthetic valve obstruction due to thrombus or pannus is still a serious valve-related complication.¹⁸ The Ross procedure, despite being excellent, may have the risk of pulmonary autograft failure.^{10,11}

In the last 2 decades, repair or reconstruction of the aortic valve has become an increasingly attractive alternative to conventional AVR.^{19–21} The first repair approaches were focused on correcting the prolapse of the fused cusp by shortening its free margin.²² In addition, triangular resection of abnormal cusp tissue and insertion of a pericardial patch were introduced as feasible procedures.^{23–25} Various aortic valve repair techniques have been reported with good results. Many of them used bicuspidization.

With the congenital BAV, AS might occur at a mean age younger than 60 years,⁴ and AR might develop at a mean age younger than 30 years.^{4,5} As Leonardo da Vinci noticed in the 16th century, BAV has less hemodynamic efficiency than tricuspid aortic valve. This has been proven over time by the differences in the natural history of people with native tricuspid aortic valve and BAV. Moreover, although the exact mechanism of proximal aortic dilatation has not been clarified, the significantly higher shear forces might have an impact on the development of aortic dilation in patients with BAV.²⁶

Our original aortic valve reconstruction using glutaraldehyde-treated autologous pericardium is pure tricuspidization, which is basically a tricuspid replacement using autologous pericardium. We believe that tricuspidization is the ideal reconstructive technique rather than bicuspidization. Tricuspidization can make the total free margin length of aortic valve cusps longer than bicuspidization. In a bicuspid valve, the movement of the cusps is very different from that of a tricuspid valve. The cusps in a bicuspid valve are usually concave in shape, where the contact point is lower than the commissural level. Because a bicuspid valve has only 2 commissures, the cusps are unable to open fully, and their movement is mostly limited to opening sideways. This restriction comes from the fact that the free margin length of the cusps is shorter than the inter-commissural distance along the annulus. In contrast, the orientation of the cusps in a tricuspid valve allows each cusp to fully open while maintaining the circular shape of the aortic valve. This is the reason why we perform our original AVRec for tricuspidization. Moreover, we raise the contact point of the cusps to the same level as the commissure, to make the cusp's free-margin length approximately equal to the inter-commissural distance along the annulus.¹² Tricuspidization is important to the full opening of the cusps. In contrast to bicuspid and tricuspid valves, the free-margin length of the cusp in a quadricuspid valve is longer than the commissural distance. This configuration also prevents each cusp from opening fully (Figure 7).

When performing original aortic valve reconstruction, it is important to remember that the aortic valve represents a collection of different-size cusps, and that the size of the aortic cusp is defined independently by the distance between the commissures. As a result, we create pericardial cusps separately for each coronary cusp, and each cusp may be a different size from the other. Based on our collected data, aortic valves represent a collection of different-size cusps. Among tricuspid patients, 13% had 3 equidistant measurements between commissures.

Fifty-seven percent of patients had 2 equidistant measurements, and the remaining 30% had 3 different distances. Therefore many of the native aortic valves have their central contact point at a different point to the real central point of the annular circle. We have been reconstructing aortic valves as naturally as possible. Tricuspid aortic valve can also produce a larger orifice area even with different size cusps, than a bicuspid valve can.

The effect of tricuspidization for full valve opening can be seen on postoperative echocardiography (Figure 8). The full opening of the valve is essential for the treatment of AS, and it is also necessary for the treatment of AR. The present study has demonstrated excellent postoperative hemodynamics after aortic valve reconstruction.

Our original aortic valve reconstruction does not require any foreign body. This results in better cost-effectiveness and possibly increased tolerance to infection. Moreover, this procedure is able to preserve the coordination of left ventricle, aortic valve annulus, aortic valve cusps, sinus of Valsalva, and sino-tubular junction to maximize aortic valve function.

One limitation of the present study was the lack of long-term follow-up. Further study with a larger number of patients and a longer follow-up period is needed.

Conclusions

Aortic valve reconstruction with glutaraldehyde-treated autologous pericardium has good short-term and mid-term results for patients with symptomatic BAV. Tricuspidization also produces good opening and closure of the aortic valve while maintaining a low pressure gradient and minimal regurgitation.

References

- De Mozzi P, Longo UG, Galanti G, Maffulli N. Bicuspid aortic valve: A literature review and its impact on sport activity. *Br Med Bull* 2008; **85**: 63–85.
- Perloff JK. The Howard Gilman Foundation Lecture. Where have we come from and where are we going? Valve management past, present and future. *Adv Cardiol* 2004; **41**: 1–8.
- Nouh MS, Al Nozha MM, Taha A, Al-Shamiri M, Arafah MR, Akhter JM, et al. Prevalence of bicuspid aortic valve and mitral valve prolapse in a healthy Saudi population and the clinical implications of their association. *Ann Saudi Med* 1996; **16**: 417–419.
- Roberts WC. Congenitally bicuspid aortic valve: A study of 85 autopsy cases. *Am J Cardiol* 1970; **26**: 72–83.
- Olson LJ, Subramanian R, Edwards WD. Surgical pathology of pure aortic-insufficiency: A study of 225 cases. *Mayo Clin Proc* 1984; **59**: 835–841.
- Aicher D, Kuniyara T, Abou IO, Brittner B, Graber S, Schafers HJ. Valve configuration determines long-term results after repair of the bicuspid aortic valve. *Circulation* 2011; **123**: 178–185.
- Boger MA, David TE. Management of the valve and ascending aorta in adults with bicuspid aortic valve disease. *Semin Thorac Cardiovasc Surg* 2005; **17**: 143–147.
- Jamieson WRE, Burr LH, Miyagishima RT, Germann E, Macnab JS, Stanford E, et al. Carpentier-Edwards supra-annular aortic porcine bioprosthesis: Clinical performance over 20 years. *J Thorac Cardiovasc Surg* 2005; **130**: 994–1000.
- Salem DN, Stein PD, Al-Ahmad A, Bussey HI, Horstkotte D, Miller N, et al. Antithrombotic therapy in valvular heart disease: Native and prosthetic. *Chest* 2004; **126**: 457S–482S.
- De-Kerchove L, Rubay J, Pasquet A, Poncelet A, Ovaert C, Pirotte M, et al. Ross operation in the adult: Long-term outcomes after root replacement and inclusion techniques. *Ann Thorac Surg* 2009; **87**: 95–102.
- Elkins RC, Thompson DM, Lane MM, Elkins CC, Peyton MD. Ross operation: 16-year experience. *J Thorac Cardiovasc Surg* 2008; **136**: 623–630.
- Ozaki S, Kawase I, Yamashita H, Uchida S, Nozawa Y, Takatoh M, et al. A total of 404 cases of aortic valve reconstruction with glutaraldehyde-treated autologous pericardium. *J Thorac Cardiovasc Surg* 2014; **147**: 301–306.
- Ozaki S, Kawase I, Yamashita H, Uchida S, Nozawa Y, Matsuyama

- T, et al. Aortic valve reconstruction using self-developed aortic valve plasty system in aortic valve disease. *Interact Cardiovasc Thorac Surg* 2011; **12**: 550–553.
14. Kawase I, Ozaki S, Yamashita H, Uchida S, Nozawa Y, Matsuyama T, et al. Aortic valve reconstruction of unicuspid aortic valve by tricuspidization using autologous pericardium. *Ann Thorac Surg* 2012; **94**: 1180–1184.
 15. Kawase I, Ozaki S, Yamashita H, Uchida S, Nozawa Y, Matsuyama T, et al. Original aortic valve plasty with autologous pericardium for quadricuspid valve. *Ann Thorac Surg* 2011; **91**: 1598–1599.
 16. Shibayama K, Watanabe H, Tabata M, Sasaki S, Fukui T, Umemura J, et al. Impact of ejection fraction on long-term outcome after elective aortic valve replacement in octogenarians with aortic stenosis. *Circ J* 2012; **76**: 1761–1767.
 17. Handa N, Miyata H, Motomura N, Nishina T, Takamoto S. Procedure- and age-specific risk stratification of single aortic valve replacement in elderly patients based on Japan adult cardiovascular surgery database. *Circ J* 2012; **76**: 356–364.
 18. Ueda T, Teshima H, Fukunaga S, Aoyagi S, Tanaka H. Evaluation of prosthetic valve obstruction on electrocardiographically gated multidetector-row computed tomography: Identification of subprosthetic pannus in the aortic position. *Circ J* 2013; **77**: 418–423.
 19. Minakata K, Schaff HV, Zehr KJ, Dearani JA, Daly RC, Orszulak TA, et al. Is repair of aortic valve regurgitation a safe alternative to valve replacement? *J Thorac Cardiovasc Surg* 2004; **127**: 645–653.
 20. Rao V, Van Arsdell GS, David TE, Azakie A, Williams WG. Aortic valve repair for adult congenital heart disease: A 22-year experience. *Circulation* 2000; **102**(Suppl): III40–III43.
 21. Veldman GR, Connolly HM, Orszulak TA, Dearani JA, Schaff HV. Fate of bicuspid aortic valves in patients undergoing aortic root repair or replacement for aortic root enlargement. *Mayo Clin Proc* 2006; **81**: 322–326.
 22. Cosgrove DM, Rosenkranz ER, Hendren WG, Bartlett JC, Stewart WJ. Valvuloplasty for aortic insufficiency. *J Thorac Cardiovasc Surg* 1991; **102**: 571–576.
 23. Casselman FP, Gillinov AM, Akhrass R, Kasirajan V, Blackstone EH, Cosgrove DM. Intermediate-term durability of bicuspid aortic valve repair for prolapsing leaflet. *Eur J Cardiothorac Surg* 1999; **15**: 302–308.
 24. Tolan MJ, Daubeney PE, Slavik Z, Keeton BR, Salmon AP, Monro JL. Aortic valve repair of congenital stenosis with bovine pericardium. *Ann Thorac Surg* 1997; **63**: 465–469.
 25. Doss M, Moid R, Wood JP, Miskovik A, Martens S, Moritz A. Pericardial patch augmentation for reconstruction of incompetent bicuspid aortic valves. *Ann Thorac Surg* 2005; **80**: 304–307.
 26. Meierhofer C, Schneider EP, Lyko C, Hutter A, Martinoff S, Markl M, et al. Wall shear stress and flow patterns in the ascending aorta in patients with bicuspid aortic valves differ significantly from tricuspid aortic valves: A prospective study. *Eur Heart J Cardiovasc Imaging* 2013; **14**: 797–804.