Background. Aortic valve reconstruction surgery (AVRS), consisting of aortic leaflet reconstruction with tailored pericardial patches and fixation of the sinotubular junction with properly sized fabric rings, is performed for the treatment of aortic valve diseases. The early and midterm outcomes of AVRS were analyzed.

Methods. Between December 2007 and December 2012, 262 patients with isolated aortic valve disease underwent AVRS in one center. Clinical outcomes, effective orifice area, mean gradients, and left ventricular mass index were evaluated yearly.

Results. Mean follow-up duration was 36.0 ± 17.1 months and was complete in 100% of surviving patients. There was no hospital mortality, but there were 3 late deaths (1.1% late mortality). Seven patients (2.7%) required reoperation: 5 because of endocarditis and 2 because of suture disruption of the leaflets. Ten patients (3.8%) experienced neurologic events. Aortic valve regurgitation was absent or trivial in 226 patients (87.3%) and mild in 29 (11.2%), mild to moderate in 3 (1.2%), and moderate to severe in 1 (0.4%). The mean valve gradient and valve orifice area were 5.3 mm Hg and 1.3 ± 0.4 cm²/m², respectively.

Conclusions. The data from the first 5 years after AVRS reveal good clinical and hemodynamic outcomes, suggesting that AVRS is a new alternative technique to the practice of replacement with stented bioprostheses and mechanical prostheses. However, whether the reconstructed aortic valve represents a truly long-term valve remains to be demonstrated.


Most mitral and tricuspid valve diseases can be managed by valve repair, but aortic valve diseases are typically treated by prosthetic valve replacement [1]. Placement of a prosthetic valve in the aortic root base (annulus) does not preserve the dynamic function of the aortic annulus during the cardiac cycle as a result of fixation of the annulus to a prosthetic ring. Additionally, the opening area of the prosthetic valve is significantly reduced compared with that of a normal aortic valve of the same aortic annulus diameter [2]. This reduced dynamic function is more problematic with a stented bioprosthesis valve, because three stent posts are added as a skeleton for the tissue leaflets. The inappropriate design of bioprosthesis valves leads to turbulent flow across them, which imposes significant physiologic stress on the leaflets, and may be a strong factor leading to their rapid degeneration, as seen in congenital bicuspid valves [3]. Because of their limited durability, bioprosthetic valves may not currently be a good substitute for a mechanical valve in younger patients. Additionally, all prosthetic valves retain only the open and closed functions of the leaflets without annular contraction or expansion during the cardiac cycle. With aortic valve reconstruction surgery (AVRS), we expect the dynamic function of the aortic root base to be preserved, thus minimizing the reduction of the aortic opening area. This function-preserving property is especially important in patients with a small annulus. We analyzed the early and midterm outcomes of patients who underwent AVRS in one center for the treatment of aortic valve disease.

Material and Methods

We retrospectively analyzed patients who received AVRS for the treatment of aortic valve diseases at Konkuk University Medical Center between December 2007 and December 2012. Informed consent was obtained from all patients, and the study was approved by the Institutional Review Board at Konkuk University.

Selection of Patients

Aortic valve reconstruction surgery consisting of pericardial leaflet replacement and sinotubular junction (STJ)
Surgical Techniques
Aortic valve reconstruction surgery was performed using advanced surgical techniques that were modified from the previously described novel technique of aortic valvuloplasty [4, 5]. Surgery was performed through a median sternotomy under a moderate hypothermic cardiopulmonary bypass with antegrade and retrograde cold-blood cardioplegia. The diseased aortic valve was exposed and excised through a horizontal aortotomy 1.0 cm above the right coronary artery ostium.

For AVRS, first each part of the aortic root was measured, and the STJ diameter was determined. If the STJ was not dilated, STJ diameter was determined by direct measurement after aortic incision in the arrested heart. In cases with STJ dilatation, however, the new STJ diameter was determined by considering the diameter of the aortic annulus [5]. Three new commissures were marked with three inverted-Ys using a medical pen at equal intercommissural distances and root heights. The circumferential aortic wall just above the new commissures became the new STJ.

Once the STJ diameter was determined, the size of the pericardial leaflet patches for reconstruction of the aortic valve could be decided upon because the STJ diameter is the same as the length of the upper margin of each aortic leaflet. In four cases with a significant annular dilatation, the dilated fibrous annulus was reduced to the diameter of the muscular annulus with two fabric strips using six interrupted mattress sutures [6].

The next step was to manufacture new aortic leaflets with bovine pericardium (Supple Peri-Guard, Synovis, St. Paul, MN), which is the defining step of AVRS. The xenograft was tailored to make new pericardial leaflets of the exact size that would best fit the diameter of the new STJ. The length of the upper margin of the pericardial leaflet patch was designed to be the same as the diameter of the STJ, and the two lower angles of the patch were trimmed to a round shape while maintaining a patch height that was 0.7 times the length of the upper margin of the patch. To make a pericardial leaflet for real use, an extra suture margin with a 2.0-mm width was added along the suture line of the patch. To simplify the troublesome work of making new leaflet patches, we used templates that were matched to the diameter of the new STJ (Leafcon Templates, ScienCity Co, Seoul, Korea; Fig 1A). Three pericardial leaflets of the same size were attached to the cusp attachments with continuous 5-0 Prolene sutures (Ethicon, Somerville, NJ). The suture was started at the nadir (base) of each annulus and continued up to both commissures by continuous over and over suture technique in a suture interval ratio of 3:2 (Fig 1B) [5]. At each commissure, two sutures were tied inside and then drawn to outside of the aortic wall and tied again.

Fixation or reduction of the STJ, the last step of AVRS, was performed with a nonexpandable inner polyethylene terephthalate fiber (Dacron) ring and a softer outer ring or strip (ScienCity Co) at the new STJ, fixing the aorta and two rings together with 18 interrupted 4-0 polypropylene mattress sutures (Fig 2). The lower margin of the inner ring was placed at least 5.0 mm above both coronary ostia. The size of the outer ring was determined by adding 4 to 6 mm to the size of the inner ring according to the thickness of the aortic wall. Five different sizes of leaflets were used for AVRS (Table 2).

Coaptation sutures were made with a figure-eight suture method using 5-0 polypropylene at the leaflet margin at a distance of 1 to 2 mm from each commisural end of
the new leaflets. The aortotomy was subsequently closed in a conventional manner.

Clinical Evaluation and Follow-Up
Preoperative and postoperative transthoracic echocardiographic studies were routinely performed before surgery, at discharge from the hospital, and then annually if there were no problems using conventional ultrasound systems (Vivid 7; GE Medical Systems, Milwaukee, WI). Postoperatively aortic valve regurgitation was graded semiquantitatively on a 1+ to 4+ scale [7].

The left ventricular mass and its indexed value were calculated using the Penn formula postulated by Devereux and Reichek [8]. Using the most recent echocardiographic data, we followed-up the aortic valve areas and valve gradients for all patients. All patient survivals and deaths were confirmed by a schedule of recent visits or by telephone, and follow-up was complete in 100% of surviving patients. An event was defined as any of the following: death from any cause, myocardial infarction, endocarditis, stroke, revascularization for new-onset angina, and redo aortic valve surgery. For this report we analyzed a total of 786.5 patient-years.

Anticoagulation Regimen
The postoperative anticoagulation regimen included oral warfarin sodium as soon as feeding was possible so that the international normalized ratio levels reached the therapeutic range of 1.75 to 2.5. Oral anticoagulation was

<table>
<thead>
<tr>
<th>Variable</th>
<th>Result</th>
</tr>
</thead>
<tbody>
<tr>
<td>Aortic cross-clamp time (min)</td>
<td>110.3 ± 21.5</td>
</tr>
<tr>
<td>Cardiopulmonary bypass time (min)</td>
<td>175.0 ± 30.8</td>
</tr>
<tr>
<td>Size of the implanted leaflets</td>
<td></td>
</tr>
<tr>
<td>22 mm</td>
<td>11 (4.2%)</td>
</tr>
<tr>
<td>24 mm</td>
<td>74 (28.2%)</td>
</tr>
<tr>
<td>26 mm</td>
<td>107 (40.8%)</td>
</tr>
<tr>
<td>28 mm</td>
<td>54 (20.6%)</td>
</tr>
<tr>
<td>30 mm</td>
<td>16 (6.1%)</td>
</tr>
<tr>
<td>Placement of the inner ring in STJ</td>
<td></td>
</tr>
<tr>
<td>No</td>
<td>14 (5.3%)</td>
</tr>
<tr>
<td>Yes</td>
<td>248 (94.7%)</td>
</tr>
<tr>
<td>Placement of the outer ring in STJ</td>
<td></td>
</tr>
<tr>
<td>No</td>
<td>1 (0.4%)</td>
</tr>
<tr>
<td>Yes</td>
<td>261 (99.6%)</td>
</tr>
<tr>
<td>Combined procedures</td>
<td></td>
</tr>
<tr>
<td>Septal myectomy</td>
<td>21 (8.0%)</td>
</tr>
<tr>
<td>Cox-maze procedure</td>
<td>8 (3.1%)</td>
</tr>
<tr>
<td>Ascending aortic wrapping</td>
<td>89 (32.4%)</td>
</tr>
<tr>
<td>Intensive care unit stay (days)</td>
<td>3.8 ± 3.7</td>
</tr>
<tr>
<td>Hospital stay (days)</td>
<td>15.1 ± 8.9</td>
</tr>
<tr>
<td>Perioperative myocardial infarction</td>
<td>0 (0%)</td>
</tr>
<tr>
<td>Reexploration for postoperative bleeding</td>
<td>9 (3.4%)</td>
</tr>
<tr>
<td>In-hospital mortality</td>
<td>0 (0%)</td>
</tr>
</tbody>
</table>

STJ = sinotubular junction.
continued for 2 months and monitored in the outpatient office. After 2 months, oral anticoagulation was terminated in the absence of any indications for permanent anticoagulation.

**Statistical Analysis**

Statistical analysis of the data was performed using SPSS 18.0 (IBM, Armonk, NY). Categorical variables were expressed as proportions (%), and continuous variables were expressed as mean ± standard deviations. Student’s t test, paired Student’s t test, and one-way analysis of variance (Tukey’s multiple comparison test) were used to analyze normally distributed continuous data. Categorical data were analyzed and compared using the χ² test and Fisher’s exact test. Survival and freedom from event probabilities were estimated using the standard nonparametric Kaplan-Meier method.

**Results**

**Early Morbidity and Mortality**

There was no in-hospital postoperative mortality. Nine patients (3.4%) required reexploration for postoperative bleeding or cardiac tamponade. One patient experienced a cerebral hemorrhage immediately after the operation and required a craniotomy. We did not observe valve-related thrombosis, embolism, or hemolysis during the early postoperative stage.

**Midterm Morbidity and Mortality**

Mean follow-up was 36.0 ± 17.1 months (range, 4.1 to 65.3 months). The late postoperative events are presented in Table 3. Neurologic events occurred in 10 patients (3.8%), of which 9 were thromboembolic and 1 was hemorrhagic; freedom from neurologic events was 95.4% ± 1.5% at 5 years. Redo aortic valve surgery was performed in 7 patients (2.7%; Fig 3). Among those, 2 patients experienced suture disruption of the pericardial leaflets, which was treated with resuturing. The other 5 patients had endocarditis affecting the aortic valve. One of them underwent a second AVRS, 3 received mechanical valve replacements, and another underwent a bioprosthetic valve replacement. The patient who underwent redo AVRS after endocarditis also had pulmonary valve endocarditis and simultaneously underwent pulmonary valve replacement with a stentless aortic heterograft.

One patient underwent coronary stenting for right coronary artery stenosis at 3 months after AVRS, and another patient underwent off-pump coronary artery bypass graft surgery for left anterior descending artery stenosis at 19 months after AVRS.

All-cause mortality occurred in 3 patients (1.1%). A 60-year-old man died undergoing redo valve replacement at 7 months after AVRS owing to low cardiac output syndrome. A 58-year-old man died of duodenal cancer at 32 months after AVRS. The last death occurred in a 52-year-old man as a result of a stroke at 26 months after AVRS. The 5-year cumulative survival rate was 98.4% ± 0.9% and the event-free survival was 92.0% ± 2.2% (Fig 4).

**Competence of the Pericardial Aortic Valves**

Echocardiographic data taken 23.7 ± 16.4 months postoperatively show that aortic valve regurgitation was absent or trivial in 226 (87.3%) of 259 surviving patients, mild in 29 (11.2%), mild to moderate in 3 (1.2%), and moderate to severe in 1 (0.4%). During the follow-up period we did not observe any structural dysfunction of the new leaflets. No patients showed aggravated motion limitations of the reconstructed valve leaflets (Fig 5).

**Gradients and Effective Orifice Areas of the Pericardial Aortic Valves**

At the end of follow-up, the mean values of the peak and mean gradients were 20.1 ± 9.2 mm Hg and 10.6 ± 5.3 mm Hg, respectively, and the mean aortic effective orifice area and its indices were 2.2 ± 0.7 cm² and 1.3 ± 0.4 cm²/m², respectively.
Both peak and mean gradients were significantly lower in the larger leaflets compared with the smaller leaflets (22-mm versus 26-mm leaflets, mean gradients 15.1 ± 3.1 versus 9.8 ± 3.9 mm Hg, respectively; \( p = 0.003 \)). The aortic valve orifice area index was larger in the 26-mm or larger leaflets than in the 22-mm leaflets (22-mm versus 26-mm leaflets, 1.0 ± 0.2 versus 1.3 ± 0.3 cm²/m², respectively; \( p = 0.044 \); Table 4).

Four patients (1.5%) had mean gradients greater than 25 mm Hg, of which 2 had 24-mm leaflets implanted, 1 had 26-mm leaflets, and another had 28-mm leaflets. Their mean gradients were 35, 36, 31, and 26.8 mmHg, respectively, and their effective orifice area indices were 0.92, 0.76, 0.8, and 0.97 cm²/m², respectively.

**Regression of Left Ventricular Hypertrophy**

The left ventricular mass index, a measure of left ventricular hypertrophy, was followed in 105 of 122 patients with preoperative aortic valve stenosis. Seventeen patients who had no follow-up data owing to their recent surgery were exempt from this follow-up. The left ventricular mass indexes had 19.6% regression compared with preoperative measures (123.4 ± 37.1 g/m² versus 94.2 ± 23.6 g/m²; \( p < 0.0001 \)) at a mean follow-up time of 23.7 ± 16.4 months (Fig 6).

**Comment**

In the aortic root that contains the aortic valve, the aortic annulus is very dynamic during the cardiac cycle [9]. With AVRS, the aortic annulus was preserved functionally as well as anatomically. Placement of small prosthetic valves [10] or stented bioprosthetic valves frequently caused a significantly high valve gradient and turbulent flow because of the small opening area. Aortic valve reconstruction surgery had no sewing ring or struts that could reduce the valve opening area. Only the diseased leaflets were replaced with pericardial leaflets, thus preserving the annulus. Different size pericardial leaflets were used, and the size selection was determined by the patient’s STJ diameter. As the STJs were fixed within a normal range of the diameter [11], the replacement valves developed no gradient or only a trivial gradient. In echocardiographic follow-up, the reconstructed valve leaflets showed the same motion as the native ones. We have never seen even trivial structural dysfunction, except for in cases of endocarditis. The mean effective orifice area of the reconstructed aortic valves was 2.2 cm², which was larger than that (1.6 to 1.8 cm²) of the established stentless valves [12–15].

The 26-mm pericardial leaflets that were most frequently used had low mean gradients of less than 10 mm Hg. Only 4 patients had pressure gradients greater than 25 mm Hg, which were not related to the leaflet sizes. Their valve area indices revealed no significant patient–prosthesis mismatch.

Of all the potential materials for reconstructing aortic leaflets, including autologous pericardium, bovine pericardium, equine pericardium, and polytetrafluoroethylene patches, bovine pericardium appears to be the
Table 4. Follow-Up Echocardiographic Findings According to Leaflet Sizes

<table>
<thead>
<tr>
<th>Leaflet Size</th>
<th>22 mm (n = 11)</th>
<th>24 mm (n = 74)</th>
<th>26 mm (n = 107)</th>
<th>28 mm (n = 54)</th>
<th>30 mm (n = 16)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Peak gradient (mm Hg)</td>
<td>28.6 ± 5.7 &lt;sup&gt;a&lt;/sup&gt;</td>
<td>24.1 ± 11.0 &lt;sup&gt;ab&lt;/sup&gt;</td>
<td>18.5 ± 6.6 &lt;sup&gt;bc&lt;/sup&gt;</td>
<td>18.1 ± 8.8 &lt;sup&gt;bc&lt;/sup&gt;</td>
<td>13.9 ± 8.6 &lt;sup&gt;c&lt;/sup&gt;</td>
</tr>
<tr>
<td>Mean gradient (mm Hg)</td>
<td>15.1 ± 3.1 &lt;sup&gt;a&lt;/sup&gt;</td>
<td>13.0 ± 6.3 &lt;sup&gt;ab&lt;/sup&gt;</td>
<td>9.8 ± 3.9 &lt;sup&gt;bc&lt;/sup&gt;</td>
<td>9.4 ± 5.0 &lt;sup&gt;c&lt;/sup&gt;</td>
<td>7.0 ± 5.1 &lt;sup&gt;c&lt;/sup&gt;</td>
</tr>
<tr>
<td>EOAI (cm²/m²)</td>
<td>1.0 ± 0.2 &lt;sup&gt;a&lt;/sup&gt;</td>
<td>1.1 ± 0.2 &lt;sup&gt;ab&lt;/sup&gt;</td>
<td>1.3 ± 0.3 &lt;sup&gt;bc&lt;/sup&gt;</td>
<td>1.5 ± 0.4 &lt;sup&gt;c&lt;/sup&gt;</td>
<td>1.7 ± 0.5 &lt;sup&gt;d&lt;/sup&gt;</td>
</tr>
</tbody>
</table>

<sup>abcde</sup> The same superscripts indicate no significant differences between groups based on Tukey’s multiple comparison test.

Statistical significances (p < 0.05) were tested by one-way analysis of variance among groups.

EOAI = effective orifice area index.

best option because of its flexibility and easy handling. We no longer use a leaflet extension procedure that augments the native leaflets with pericardial patches for aortic valve repair because the native leaflets and the augmenting pericardial patches differ in their flexibility and consistency, and the suture line between the two structures becomes thickened and limits leaflet motion.

Most cardiac surgeons are concerned with pericardial leaflet durability. Although the follow-up period is not long enough to make definitive conclusions, we have never seen even trivial leaflet movement changes on echocardiography. The bovine pericardium that we used was one of the pericardia well prepared by an adequate fixation process. A 16-year follow-up of aortic valve reconstruction with bovine and autologous pericardium in young adult patients showed no difference in freedom from structural valve degeneration between two pericardial groups [16].

Three main points argue for AVRS as a well-engineered surgical technique: (1) the pericardial leaflets are made in the ideal sizes for individual patients, (2) the flat patches are changed into a scoop-shaped leaflet by a 3:2 plication suture technique, and (3) the STJ fixation maintains leaflet coaptation and prevents STJ dilatation [4, 5]. The leaflets were mathematically and scientifically designed in size to form a sufficient coaptation height under a certain STJ diameter.

In the past, pericardial leaflets were appropriately designed to reconstruct the aortic valve [17]. However, without the STJ fixation, the STJ would be dilated immediately after release of the aortic cross-clamp, leading to failure of the leaflet coaptation. Additionally, because the STJ diameter changes during the cardiac cycle, the leaflets do not maintain a constant coaptation. The luminal area of the STJ also increases with age [18]. Therefore, STJ fixation is an important procedure for persistent coaptation of the reconstructed valves.

We expect favorable long-term durability of the new pericardial leaflets because the low valve gradient with AVRS can reduce turbulent damage to the aortic cusps [19] and reduced exposure of the new surface to attaching osteopontin during the healing process may reduce the development of calcification [20, 21].

This study has several limitations. First, this is a retrospective study without a control group. However, as most of the patients with aortic valve disease underwent AVRS, the outcomes may indirectly be compared with those of previous valve replacement patients. This study requires long-term follow-up as there was no structural valve dysfunction during a short mean period of only 3.0 years. We could view the dynamic motion of the aortic annulus on echocardiograms of all patients, but we did not perform a quantitative analysis for all patients. Although the incidence of postoperative main events, including neurologic events and endocarditis, was not high, the occurrence of these morbidities should not be overlooked.

In conclusion, the early and midterm clinical results in the patients undergoing AVRS were satisfactory, but it is necessary to continue monitoring patients who underwent AVRS to observe long-term durability and hemodynamic properties of the reconstructed valves.

This paper was supported by research funds from Chonbuk National University, Jeonju, and Konkuk University Medical Center, Seoul, South Korea.

None of the authors of our manuscript have any relationship with the ScienCity company that represents a conflict of interest. Meong Gun Song, MD, designed the rings for sinotubular junction fixation. He is only a minor stockholder because he received a reward for the design, but now he is not a consulting surgeon for the company and he has no financial relationship with the company.
References


