Time Course of Aortic Valve Function and Root Dimensions After Subcoronary Ross Procedure for Bicuspid Versus Tricuspid Aortic Valve Disease

Claudia Schmidtke, MD; Matthias Bechtel, MD; Michael Hueppe, PhD; Hans-H. Sievers, MD, FETCS

Background—The freestanding aortic root, which is the currently preferred operative technique for pulmonary autografts, is reported to dilate and potentially promote aortic insufficiency, which has led to a controversial debate on the appropriate surgical technique, especially for congenital bicuspid aortic valve disease. Desirable data on the time course of valve function and root dimensions for the alternative subcoronary technique comparing bicuspid and tricuspid aortic valve disease are scarce.

Methods and Results—Echocardiographic examinations of 31 patients with congenital bicuspid aortic valve disease (group A; age 50.5±11.0 years) and 51 patients with acquired tricuspid aortic valve disease (group B; age 48.1±15.7 years) who were operated on between June 1994 and August 1998 were performed twice postoperatively. At first and second follow-up, respectively, maximum (mean) pressure gradients were 6.0±2.0 (3.6±1.0) and 5.1±2.1 (2.9±1.1) mm Hg in group A and 6.5±3.5 (3.9±1.9) and 5.0±1.7 (2.9±1.0) mm Hg in group B (P>0.05 between groups). In group A, grade 0 aortic insufficiency at first and second follow-up occurred in 8 and 7 patients, respectively, grade 0-1 in 12 and 9 patients, grade I in 9 and 11 patients, grade I-II in 1 and 0 patients, and grade II in 1 and 4 patients; in group B, grade 0 aortic insufficiency occurred in 16 and 18 patients, grade 0-I in 16 and 8 patients, grade I in 17 and 21 patients, grade I-II in 0 and 1 patient, and grade II in 0 and 1 patient (P>0.05). Aortic insufficiency decreased in 10 patients (17%). However, there was an overall tendency for aortic insufficiency to increase over time (n=23, 38%), although it remained subclinical. Aortic root dimensions did not differ between groups and were constant during follow-up.

Conclusions—This study provides some evidence that the function of the subcoronary pulmonary autograft in bicuspid aortic valve disease is excellent, with stable root dimensions, and is not different from that of tricuspid aortic valves at least up to 5.5 years postoperatively, which suggests the subcoronary technique should be reconsidered. (Circulation. 2001;104[suppl I]:I-21-I-24.)

Key Words: heart diseases • valves • pulmonary autograft

The first successful clinical use of the pulmonary autograft for aortic valve replacement was reported by Ross in 1967. With its advantages as a viable autologous transplant, the Ross procedure gained increasing acceptance as an attractive alternative for aortic valve replacement; the currently preferred operative technique is use of the freestanding root. The behavior of pulmonary autografts in patients with congenital bicuspid or acquired tricuspid aortic valve disease may be different because of connective tissue disorders in patients with bicuspid aortic valves. David et al recently reported on dilatation of the autograft freestanding root and increased aortic insufficiency, especially in patients with bicuspid aortic valves. A controversial discussion has thus begun concerning the appropriate surgical technique. We went back to the original subcoronary technique 7 years ago because we were concerned about structural alterations after pressure loading of the pulmonary root during banding of the pulmonary trunk, although our first freestanding pulmonary roots did not show progressive dilatation up to 21 months postoperatively.

Patients
From June 1994 to August 1998, 33 patients (28 men and 5 women aged 22.5 to 68.6 years) with a diseased bicuspid aortic valve (group A) and 53 patients (39 males and 14 females aged 15.1 to 70.5 years) with an acquired tricuspid aortic valve disease (group B) underwent the Ross procedure by the subcoronary technique (a total of 104 procedures were performed, including root inclusion in 17 patients, freestanding root in 1 patient, and subcoronary technique in 86 patients). There was 1 hospital cardiac death in group A and 1 late noncardiac death each in group A and group B; 1 patient was lost to follow-up in group B. Underlying diseases for the studied patients in
groups A and B, respectively, were aortic insufficiency in 9 and 23 patients, aortic stenosis in 15 and 24 patients, combined aortic valve disease in 7 patients and 1 patient, and endocarditis in 1 patient and 13 patients (3 acute).

Operative Technique
Operations were performed with standard cardiopulmonary bypass with a membrane oxygenator (Hollow Fiber Oxygenator, Spiral Gold, Baxter) at moderate hypothermia (26°C nasopharyngeal temperature) with antegrade cold crystalloid cardioplegia (St Thomas’ solution) for myocardial protection. The subcoronary technique was performed as described in detail elsewhere.9 The aorta was opened in an S shape through the noncoronary aortic sinus down to the annulus. An annuloplasty for reduction of annulus diameter according to David et al9 using a piece of Dacron graft was performed in 8 group A and 7 group B patients. The sinotubular junction was matched to the diameter of the autograft. We used no circumferential stabilization of the sinotubular junction or the annulus with Dacron fabric. The right ventricular outflow tract was reconstructed with a cryopreserved pulmonary homograft in all patients. Concomitant procedures in group A and group B, respectively, were replacement of the ascending aorta in 2 patients and 1 patient, reconstruction of the ascending aorta in 5 and 6 patients, mitral valve repair in 3 and 2 patients, Maze procedure in 2 and 0 patients, CABG in 1 patient and 4 patients, tricuspid valve repair in 0 patients and 1 patient, and closure of a ductus arteriosus Botalli in 0 patients and 1 patient.

Echocardiographic Data Acquisition and Measurements
Informed written consent was obtained before echocardiography. Investigative procedures were in accordance with institutional guidelines. All patients underwent transthoracic echocardiographic examinations twice between February 1998 and March 2000 with respective follow-ups of 17.7±9.7 and 35.0±9.6 months in group A and 18.9±14.5 and 36.2±14.5 months in group B. Transthoracic echocardiograms were made with 2.5-MHz ultrasound transducers (Hewlett-Packard Sonos 2000 system) and recorded on VHS videotape. Average values of 5 consecutive beats were taken for dimensions and pressure gradients.

2D Echocardiography
Autograft dimensions were measured as described by Roman et al11 at 3 different levels: (1) annulus at the level of the autograft leaflet hinges, (2) sinus of Valsalva at the largest anteroposterior diameter, and (3) supra-aortic ridge level at the distal rim of the sinuses of Valsalva. Measurements of diameters were made perpendicular to the long axis of the aorta in views showing the smallest and largest dimensions during cardiac cycles. The average value of smallest and largest diameter was taken. Left ventricular outflow tract diameter was obtained by freeze-frame at maximum aortic valve leaflet opening in systole. Left ventricular end-systolic and end-diastolic volumes were obtained from standard apical views. Diastole was defined as the beginning of the QRS complex on the simultaneous ECG recording.

Continuous-Wave, Pulsed, and Color Flow Doppler
Maximum velocities across the neoaortic valve were obtained by continuous-wave Doppler with the apical 5-chamber view. Aortic regurgitation was assessed by multiple techniques: pulsed wave Doppler and color flow Doppler imaging were used for mapping the left ventricular outflow tract, including determination of ratio of jet height to left ventricular outflow tract height; continuous Doppler imaging was applied to measure the deceleration slope and pressure half-time of the aortic regurgitant jet. Trace aortic insufficiency (grade 0-I) was defined as a very tiny regurgitant jet in early diastole (near detection limit). Grade I aortic regurgitation jets were present only in the left ventricular outflow tract immediately below the aortic valve; grade II jets extended to the tips of the mitral leaflets.12

Calculations
Peak systolic pressure gradient across the aortic valve (ΔP max) was calculated by the modified Bernoulli equation

$$\Delta P_{\text{max}} = 4 \times v^2$$

where v is peak systolic velocity across the aortic valve.

Statistical Analysis
Frequencies are given as absolute numbers and relative percents. Continuous data are presented as mean±SD in text and tables, except where otherwise stated. Data were analyzed by nonparametric tests. To test for differences between groups at a given point in time, data were compared by Mann-Whitney U test. Categorical data were compared by Fisher’s exact test. To analyze changes in variables between the 2 investigations, the paired Wilcoxon test was used. To test whether these changes differed between groups, the differences of the 2 measurements were compared by Mann-Whitney U test. To investigate whether these changes differed according to the change in autograft regurgitation, the Kruskal-Wallis H test was used. In addition, the association between group and the change in aortic regurgitation was analyzed by configured frequency analysis.13 Statistical significance was set at a P value <0.05. Statistical analyses were performed with statistical software (SPSS for Windows 9.0; SPSS, Inc).

Results
The pressure gradient across the autograft declined in both groups (P<0.001): the instantaneous pressure gradient decreased from 6.0±2.0 to 5.1±2.1 mm Hg in group A and from 6.5±3.5 to 5.0±1.7 mm Hg in group B (Table). Autograft regurgitation increased over time (P=0.013), with no significant differences between groups (Figures 1 and 2). No neoaortic insufficiency greater than grade II occurred. Data are depicted in the Table.

Aortic root diameters at the annulus, sinus, and supra-aortic ridge level were comparable between groups and did not change significantly over time (Table). Hemodynamic data, expressed as left ventricular ejection fraction, fractional shortening, and cardiac output, were comparable between groups (Table). Parameters such as systolic and diastolic blood pressure, aortic root dimensions (annulus, sinus, and supra-aortic ridge level), age, sex, cardiac output, and aortic annuloplasty according to David did not influence the change in aortic insufficiency (P>0.05).

Discussion
In this study, we could not detect any difference in hemodynamics of pulmonary autografts in the subcoronary position or in the dimensions of the aortic root for patients with bicuspid or tricuspid aortic valve disease up to 5.5 years postoperatively. Bicuspid aortic valve is the most common congenital valve anomaly, with an overall incidence of 1% to 2%. It is estimated that at least one third of patients with a bicuspid aortic valve will develop serious complications.14 It often appears in association with an aortic root dilatation.15 De Sa et al16 examined the histological features of the ascending aorta and main pulmonary artery in patients with bicuspid and tricuspid aortic valves. They found more severe cystic media necrosis, elastic fragmentation, and changes in smooth muscle cell orientation in the ascending aorta and in pulmonary trunk specimens in patients with a bicuspid valve. In a certain number of patients, this may explain the dilatation of the root and ascending aorta after the Ross procedure.6,16
Although we could not detect a progressive dilatation of the aortic root up to 21 months after the operation in our first 10 patients with a freestanding aortic root,2 of them developed sinus diameters >50 mm at 7 years postoperatively.17 The duration of the high-pressure load on the autograft probably has a dilating effect on the pulmonary root, but this remains to be established in other studies with more patients and a longer follow-up period. Theoretically, this dilatation, especially at the sinotubular junction, may have some impact on the progression of aortic insufficiency, which was reported to occur occasionally after the Ross procedure especially if the freestanding root technique was used.6 In the present series using the subcoronary technique, the dimensions of the root did not change in patients with either bicuspid or tricuspid valve disease, nor did the diameter of the root increase over time. The dilatation-protecting effect of the wall of patients’ native aortic roots may have contributed to this effect. Nevertheless, a progression of aortic insufficiency was observed in both groups, although this change was in the subclinical range, not exceeding grade II aortic insufficiency. Chambers et al18 and Elkins19 demonstrated that aortic regurgitation progressed when the subcoronary technique was used. Whether aortic insufficiency in patients in the present study will increase further remains to be evaluated. Careful follow-up in these patients is certainly necessary. However, an increase in aortic insufficiency has also been observed in patients with a freestanding autograft aortic root.20

We investigated several parameters that could be causative of increasing aortic insufficiency, such as diastolic blood pressure, aortic root dimensions, age, and sex, but could not observe a statistically significant difference between those with increasing aortic regurgitation and those with stable valve function. Other factors are probably associated with an observed increase in aortic insufficiency, such as interobserver variability of echocardiographic investigations, the result of minor mismatches in size and spatial arrangement.

Figure 1. Time course of aortic insufficiency (AI) after Ross procedure in bicuspid aortic valve disease. n indicates number of patients; abscissa, date of investigation; and ordinate, grade of aortic insufficiency.

Figure 2. Time course of aortic insufficiency (AI) after Ross procedure in tricuspid aortic valve disease. n indicates number of patients; abscissa, date of investigation; and ordinate, grade of aortic insufficiency.

### Root Dimensions and Valve and Heart Function After Ross Procedure

|                    | Group A (Bicuspid Aortic Valve) | Group B (Tricuspid Aortic Valve) | \(\rho\)  
<table>
<thead>
<tr>
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</thead>
<tbody>
<tr>
<td></td>
<td>Follow-Up I</td>
<td>Follow-Up II</td>
<td>Follow-Up I</td>
</tr>
<tr>
<td>n (M/F)</td>
<td>31 (27/4)</td>
<td>31 (27/4)</td>
<td>51 (37/14)</td>
</tr>
<tr>
<td>Follow-up, mo (range)</td>
<td>17.7±3.0 (9.2--36.0)</td>
<td>35.0±9.6 (15.4--55.1)</td>
<td>18.9±14.5 (0.1--49.1)</td>
</tr>
<tr>
<td>dPmax, mm Hg</td>
<td>6.0±2.0</td>
<td>5.1±2.1</td>
<td>6.5±3.5</td>
</tr>
<tr>
<td>dPmean, mm Hg</td>
<td>3.6±1.0</td>
<td>2.9±1.1</td>
<td>3.9±1.9</td>
</tr>
<tr>
<td>AI, n (%)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Grade 0</td>
<td>8 (25.8)</td>
<td>7 (22.6)</td>
<td>18 (35.3)</td>
</tr>
<tr>
<td>Grade 0–I</td>
<td>12 (38.7)</td>
<td>9 (29.0)</td>
<td>16 (31.7)</td>
</tr>
<tr>
<td>Grade I</td>
<td>9 (29.0)</td>
<td>11 (35.5)</td>
<td>17 (33.3)</td>
</tr>
<tr>
<td>Grade I–II</td>
<td>1 (3.2)</td>
<td>0 (0)</td>
<td>0 (0)</td>
</tr>
<tr>
<td>Grade II</td>
<td>1 (3.2)</td>
<td>4 (12.9)</td>
<td>0 (0)</td>
</tr>
<tr>
<td>Annulus, mm</td>
<td>23.5±2.4</td>
<td>22.4±2.3</td>
<td>23.0±3.5</td>
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<tr>
<td>Sinus, mm</td>
<td>32.5±3.2</td>
<td>31.5±3.1</td>
<td>30.9±4.3</td>
</tr>
<tr>
<td>Supra-aortic ridge, mm</td>
<td>28.2±2.5</td>
<td>27.6±2.6</td>
<td>27.0±3.8</td>
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<tr>
<td>LV EF, %</td>
<td>61.6±7.8</td>
<td>61.3±8.8</td>
<td>62.0±10.7</td>
</tr>
<tr>
<td>LV FS, %</td>
<td>30.9±7.8</td>
<td>33.7±7.0</td>
<td>31.4±8.9</td>
</tr>
<tr>
<td>CO, L/min</td>
<td>6.4±1.7</td>
<td>5.7±1.4</td>
<td>6.3±2.1</td>
</tr>
<tr>
<td>Systolic BP, mm Hg</td>
<td>130.0±27.6</td>
<td>131.8±17.6</td>
<td>133.7±34.3</td>
</tr>
<tr>
<td>Diastolic BP, mm Hg</td>
<td>83.5±12.7</td>
<td>84.1±12.3</td>
<td>79.7±13.8</td>
</tr>
</tbody>
</table>

*Significance for group A vs group B.

dPmax indicates maximum pressure gradient across autograft; dPmean, mean pressure gradient across autograft; AI, aortic insufficiency; LV EF, left ventricular ejection fraction; LV FS, left ventricular fractional shortening; CO, cardiac output; and BP, blood pressure.
during implantation, and some type of degeneration of the leaflet tissue after initially trivial aortic insufficiency. This latter assumption is underlined in the present study by the fact that worsening of aortic insufficiency occurred mainly from initial grade 0-I to grade II. Increase of aortic insufficiency from grade 0 occurred less frequently, in only 1 patient. On the other hand, a decrease in aortic insufficiency was observed in 10 patients. Whether this is related to a type of adaptation\textsuperscript{20} or to inaccuracy of echocardiographic techniques is unclear.

The present study has several shortcomings. The time interval between the first and second follow-up was relatively short and should be extended to draw more meaningful conclusions. There were only 2 echocardiographic studies per patient, and thus the characteristic of the time course of the different parameters could not be defined. All operations were performed by a single surgeon, who certainly has a bias concerning the details of operative techniques in the context of the local anatomy.

In conclusion, we provide some evidence that the hemodynamic results of autografts in the subcoronary position are excellent and that the dimensions of the aortic root remain stable, with no difference between patients with a congenital bicuspid aortic valve or acquired tricuspid aortic valve disease, at least up to 5.5 years postoperatively. This may have bearing on the judgment of the appropriate surgical technique with the pulmonary autograft for the different pathological entities of the aortic valve.

References
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