Impact of Preoperative Aortic Root Diameter on Long-Term Aortic Valve Function After Valve Sparing Aortic Root Reimplantation

R.G. Leyh, MD, PhD; K. Kallenbach, MD; M. Karck, MD, PhD; C. Hagi, MD; S. Fischer, MD, MSC; A. Haverich, MD, PhD

Methods and Results—From July 1993 to October 2001, 168 patients with aortic root aneurysm underwent valve sparing aortic root reimplantation. Patients with type A aortic dissection were excluded. Thus, 123 patients were analyzed. We identified 47 patients with an preoperative aortic root diameter exceeding 60 mm (group A), 58 patients with an diameter between 50 and 60 mm (group B), and 18 patients with a diameter less than 50 mm (group C). The groups were compared regarding mortality, long-term survival, freedom from reoperation, freedom from severe and moderate aortic valve insufficiency (AI), and postoperative morbidity. Mean follow-up (group A 43±26 months, group B 40±25 months, group C 23±19 months; group C versus group A, P=0.005; group C versus group B, P=0.011) was shorter in group C. Perioperative mortality (group A 2.2%, group B 1.9%, group C 5.2%; P=ns) was comparable between the groups with each one patient. The 3-year survival for group A was 98±2%, for group B 96±3%, and for group C 100±0% (P=ns). Freedom from reoperation for group A was 98±2%, for group B 96±3%, and for group C 88±8% (P=ns). Four patients developed severe or moderate AI, thus freedom from severe and moderate AI for group A was 100±0%, for group B 88±8%, and for group C 94±5% (P=ns). During follow-up no thromboembolic or bleeding events were noticed.

Conclusions—Our data show that the preoperative diameter of the aortic root has no impact on the longevity of the repair. Thus, the reimplantation technique can be recommended for all patients presenting with an aortic root aneurysm and normal leaflets regardless of the aortic root diameter. (Circulation. 2003;108[suppl II]:II-285-II-290.)

Key Words: aorta □ aneurysm □ valves □ survival

Valve sparing aortic root operations have shown excellent mid-term results with low re-operation rates and low valve related morbidity.1–3 Although these techniques have gained wide acceptance within the last years there is still no agreement which patient will profit most, and in which patients these techniques is associated with an increased risk of premature failure. Aneurysms of the ascending aorta and aortic root are frequently associated with aortic valve regurgitation because of outward displacement of aortic valve commissures.4,5 Furukawa and coworkers demonstrated that isolated dilation of the sinus of Valsalva does not cause aortic valve regurgitation.6 However, significant dilation of the sinus may cause dilatation of the sinotubular junction and/or the aortic annulus with subsequent aortic valve regurgitation in the presence of macroscopically normal aortic leaflets. In these patients aortic valve competence can be re-established with valve sparing aortic replacement procedures.1–3 Tambeur and coworkers assumed a positive correlation between aortic root diameter and increased mechanical leaflet stress and speculated that valve-sparing aortic root replacement procedures in patients with a preoperative aortic root diameter in excess of 55 mm might lead to premature failure of the repair.7 To quantify the affect of aortic root dilatation on leaflet stress and strain, Grande-Allen and associates utilized a finite element model and demonstrated progressive increases in the peak average valve stress and strain with increasing amounts of root dilatation.8 These results could have an affect on valve-sparing aortic root replacement procedures.

To address the potential impact of preoperative aortic root diameter on the longevity of the repair we analyzed the affect of preoperative aortic root diameter on aortic valve function after valve-sparing aortic root reimplantation.

Patients and Methods
Between July 1993 and October 2001, 168 patients with aortic root aneurysms underwent valve sparing aortic root reimplantation ac-
Echocardiographic Data Acquisition and Measurements
Routine intraoperative assessment of the aortic valve function was performed using transesophageal echocardiography. In all survivors valve function was assessed by transthoracic echocardiography in the left lateral decubitus position at yearly intervals. A modified ECG lead I was continuously recorded and blood pressure was measured by cuff sphygmomanometry (Dinamap, Siemens). Aortic regurgitation was assessed by color-flow Doppler techniques in the standard transesophageal views and graded as follows using the ratio of jet height/left ventricular outflow tract height:9 ratio of jet height/right ventricular outflow tract height:9 ratio of jet height/aortic sinuses of Valsalva. Aortic regurgitation grade IV was defined as jet crossing the LVOT, grade III impassable plane between the cusps and the LVOT, grade II cusp prolapse into the LVOT, grade I cusp prolapse into the intercommissural space. Thus 123 patients (83 males, 40 females; age 55±16 years; range 20 to 79 years) were analyzed. According to the preoperative aortic root diameter (mid-level of the sinus of Valsalve), obtained from pre-operative chest CT-scans, patients were divided into three groups. We identified 47 patients with an aortic root diameter exceeding 60 mm (group A, 73.3±10 mm), 58 patients with an aortic root diameter between 50 and 60 mm (group B, 55.3±4.7 mm), and 18 patients with a diameter less than 50 mm (group C, 39.3±5.7 mm). Patients preoperative data are depicted in Table 1.

Operative Technique
Standard cardiopulmonary bypass with a membrane oxygenator and systemic moderate hypothermia (28°C to 32°C) was used in all patients. In cases with aortic arch aneurysms moderate hypothermic circulatory arrest with cold (15°C) antegrade cerebral perfusion was utilized. The operative technique was described in detail elsewhere.10 In brief, after excision of the sinuses of Valsalve up to a rim of 2 to 3 mm of aortic wall and thorough mobilization of the aortic root, mattress sutures were placed through the commissures and the diameter of the prosthesis was calculated by stretching the three commissures in a vertical direction while observing the position of the commissures. Therefore, stretching of the prosthesis has to be avoided, since this would result in a too low commissure attachment height with subsequent cusp prolapse.

Protocol
Valve performance, complications, and outcome analysis are reported as suggested by the guideline of the American Association for Thoracic Surgery/Society of Thoracic Surgeons.11

Statistical Analysis
Continuous variables are expressed as mean ± SD. All data analyses were performed with SPSS 11.0 for Windows (SPSS, Chicago, IL). The Kaplan-Meier survival estimates were used to analyze long-term survival, freedom from reoperation as well as freedom from aortic valve regurgitation ≥ grade II. Statistic differences in Kaplan-Meier survival estimates were determined by using the log-rank test. Comparison of not normally distributed variables between groups were performed by using the nonparametric Kruskal-Wallis H-Test. If statistically different at a level of probability that is less than 0.05 pairwise, post hoc comparison was achieved by means of the Mann-Whitney-U test. Nominal variables were compared by using Pearson’s chi-square test or Fisher exact test for the analysis of contingency tables. A value of P <0.05 was considered significant. Statistical analyses were done without alpha adjustments, and therefore results are considered mainly exploratory.12

Results
Perioperative Outcome
There were 3 hospital death with 1 patient in each group (group A 2.1%, group B 1.7%, group C 5.6%; P>0.2). One patient died of a myocardial infarction on POD 2, the other 2 patients died of multiorgan failure on POD 4 and 17, respectively. The operative morbidity in each subgroup of patients is depicted in Table 2.

Follow-Up
Mean follow-up was 38.1±25.8 months and were complete for all hospital survivors. Mean follow-up for patients with an aortic root diameter less than 50 mm (group C) was shorter (22.9±20 months), compared with patients with an diameter exceeding 60 mm (group A) (42.8±26.5 months, P=0.005), and an diameter between 50 and 60 mm (group B) (39.4±25.5 months, P=0.011).

Five patients died during the follow-up: 1 in group A (>60 mm), 4 in group B (50 to 60 mm), and none in group C (<50 mm). None of the death were valve related. The cause of death was mainly related to the aortic root disease. Therefore, some survival curves in Table 3 are truncated because of aortic deaths. The comparison of freedom from aortic death was performed using the log-rank test. The freedom from aortic death was shorter in group A compared to group B and C (P<0.05).

TABLE 1. Clinical Profile

<table>
<thead>
<tr>
<th>Variables</th>
<th>Group A (n=47)</th>
<th>Group B (n=58)</th>
<th>Group C (n=18)</th>
<th>P-value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mean age ±SD</td>
<td>53±19</td>
<td>53±18</td>
<td>44±18</td>
<td>&gt;0.2</td>
</tr>
<tr>
<td>Gender (M/F)</td>
<td>33/14</td>
<td>37/21</td>
<td>13/5</td>
<td>&gt;0.2</td>
</tr>
<tr>
<td>Preoperative aortic regurgitation</td>
<td></td>
<td></td>
<td></td>
<td>&gt;0.2</td>
</tr>
<tr>
<td>Grade 0</td>
<td>3 (6.4)</td>
<td>3 (5.2)</td>
<td>2 (11)</td>
<td></td>
</tr>
<tr>
<td>Grade I</td>
<td>4 (8.5)</td>
<td>6 (10.3)</td>
<td>3 (16.5)</td>
<td></td>
</tr>
<tr>
<td>Grade II</td>
<td>9 (19.1)</td>
<td>24 (41.4)</td>
<td>3 (16.5)</td>
<td></td>
</tr>
<tr>
<td>Grade III</td>
<td>26 (55.3)</td>
<td>21 (36.2)</td>
<td>9 (49.5)</td>
<td></td>
</tr>
<tr>
<td>Grade IV</td>
<td>5 (10.6)</td>
<td>4 (6.9)</td>
<td>1 (5.5)</td>
<td></td>
</tr>
<tr>
<td>Marfan syndrome</td>
<td>9 (19)</td>
<td>15 (26)</td>
<td>6 (33)</td>
<td>&gt;0.2</td>
</tr>
</tbody>
</table>

P values are for differences between the three groups of patients. Percentages are shown in parentheses. SD, standard deviation.
of death in the group A (>60 mm) patient was multiorgan failure after reoperation for aortic valve endocarditis. The causes of death in group B (50 to 60 mm) patients were because of ventricular fibrillation, dissection of the aortic arch, unknown reason and accident in 1 patient each. Survival for group A was 98±2%, for group B 96±3%, and for group C 100±0% (P=0.29) (Figure 1).

A total of 5 patients needed reoperation on the aortic root, there were 3 reoperations because of significant aortic valve regurgitation (2 patients from group B, and 1 patient from

![Figure 1. Survival in patients after valve sparing aortic root reimplantation.](image-url)
group C), 1 reoperation because of endocarditis (group A), and 1 patient (group C) was reoperated for aneurysm of the aortic arch 3.5 years after the initial operation. Because of AI grade II in combination with prolapsing leaflets, the native aortic valve has been replaced prophylactic with a mechanical prosthesis (Table 3). Detailed intraoperative analysis demonstrated that resuspension of the commissures was too low in 2 patients, leading to cusp prolapse. One patient who had inflammatory disease (Morbus Wegener) had thickened and shrunken leaflets, with histological evidence of inflammatory reaction in valve cusps, and in 1 patient technical difficulties during the initial operation led to early severe aortic valve regurgitation requiring mechanical aortic valve replacement. Thus, freedom from aortic root re-operation was 98%±2% in group A (>60 mm), 96%±3% in group B (50 to 60 mm), and 88%±8% in group C (<50 mm) without statistical significance between groups (P=0.11) (Figure 2). In addition to the 3 patients requiring aortic reoperation for significant aortic valve regurgitation one patients had aortic valve regurgitation≥grade II. Thus, freedom from aortic valve regurgitation≥grade II was 100±0% in group A, 88±8% in group, B and 94±5% in group C (P=0.19) (Figure 3).

There were no strokes, thromboembolic events or bleeding complications in any patients from either group during follow-up. The clinical status of the patients expressed as functional New York Heart Association class at the latest follow-up showed no differences between groups. All patients presented in NYHA class I or II at the latest follow-up, except of each one in NYHA III (group A) and in NYHA IV (group B).

Discussion

This study analyses the influence of preoperative aortic root diameter on aortic valve function after valve sparing aortic root replacement according to the reimplantation technique described by David and Feindel 1992.10 From the data presented, we conclude, that the preoperative aortic root diameter has no impact on the longevity of the aortic valve function after valve sparing aortic root reimplantation.

Valve sparing aortic root replacement for patients with aortic aneurysm have been propagated with encouraging results within the last decade.1–4,13–15 Due to these results the indications for valve sparing aortic root replacement have been expanded from elective patients with normal leaflets to

| **TABLE 3. Re-operation after Valve Sparing Aortic Root Re-Implantation** |
|-----------------|-------|-----------------|-------------------------------------------------|---------|
| **Group A (>60 mm)** | 74    | m               | 5 | Aortic valve endocarditis | Death |
| **Group B (50–60 mm)** | 27    | m               | 12 | Progressive valvar insufficiency because of inadequate technique of valve suspension | Alive |
| | 46    | m               | 11 | Progressive valvar insufficiency with cusp degeneration because of Wegner’s granulomatosus | Alive |
| **Group C (<50 mm)** | 9     | m               | 41 | Aortic arch replacement for aneurysm, prophylactic replacement because of AI grade II caused by leaflet prolapse | Alive |
| | 40    | f               | 0.5 | Primary valve failure because of inadequate technique of valve suspension | Alive |
patients presenting with acute type A dissection, patients with bicuspid valves, patients with aortic root reoperations, patients with concomitant cardiac surgical interventions, and patients with coexisting aortic leaflet defects. Although the limits for valve sparing aortic root replacement have not been clearly delineated so far, there are data from the literature speculating that the preoperative aortic root diameter could have an impact on long-term aortic valve function after valve sparing aortic root replacement. They speculated that aortic root dilatation (≥55 mm) is associated with an increase leaflet stress and strain before any loss of coaptation with subsequent alteration in leaflet thickness and stiffness which might lead to premature failure of the repair. This hypothesis was supported by Grande Allen and associates who demonstrated in vitro in an finite element model of aortic root dilatation a progressive increase in peak average valve stress and strain in combination with increase aortic root dilatation.

In this study we could not detect any difference in aortic valve function related to the preoperative aortic root diameter. Of all long-term survivors 91.7% (110/120) had excellent function of their native, reimplanted valve after a mean follow-up of 38.1±25.8 months. Only in 1 patient, moderate regurgitation occurred, without hemodynamic relevance. Five other patients required reoperation.Detailed intraoperative analysis in the patients demonstrated that resuspension of the commissures was too low in 3 patients, which led to cusp prolapse. One patient who had inflammatory disease (Morbus Wegener) had thickened and shrunken leaflets, with histological evidence of inflammatory reaction in valve cusps, and one patient developed an aortic valve endocarditis. None of the reoperated patients had any evidence of cusp degeneration, which we could relate to the preoperative aortic root diameter. Additionally, echocardiographic follow-up demonstrated no degenerative changes in cusps (ie, calcification, cusp perforation, or cusp thickening), in patients with larger preoperative aortic root diameter. Furthermore, in the patients with the largest preoperative aortic root diameter (group A, 73.3±10 mm) only 1 out of 47 patients needed reoperation that was not related to progressive cusp degeneration (Table 3). In the remaining patients (group A) none of the long-term survivors had an aortic valve regurgitation>grade II indicating stable aortic valve function over time (mean follow-up 42.8±26.5 months).

It seems that other factors than the preoperative aortic root diameter determine the durability of a sufficient aortic valve function after valve sparing aortic root reimplantation. Our group demonstrated that a precise surgical technique with an adequate height of resuspension leaving the leaflet coaptation area above the inferior edge of implanted Dacron prosthesis seems to be a critical technical factor responsible for adequate long-term valve function after valve sparing aortic root replacement. However, because of our experience we would not perform valve sparing aortic root reimplantation in patients presenting with systemic inflammatory disease (eg, Morbus Wegener). Whether patients requiring individual cusp manipulation to achieve valve competence may be at increased risk for premature failure of the repair is still a matter of debate. In our patient cohort in 15 patients individual leaflet manipulation was performed and none of these valves failed, however, in our opinion the small number of patients does not allow to draw final conclusions regarding this issue.

**Limitations**

The authors wish to address several limitations of the study, (1) determination of aortic root diameter by computed tomography (CT) scan may be cumbersome since the tangential size of the aorta rather than the true diameter of the ascending aorta at a right angle to the axis of the aorta may be measured in some instances. However, the analysis of aortic root diameter has been performed by experienced radiologists with a clear understanding of this problem, and repeat measurement revealed an intraobserver variability of 5.3%.
only. (2) We did not correlate the diameter of the sinotubular junction, or aortic annulus with valve failure. Because a more marked dilatation of the sinotubular junction may be associated with a higher grade of aortic regurgitation it can be argued that this might have an impact on the longevity of the repair. However, we recently showed that the degree of preoperative aortic valve regurgitation had no impact on long-term valve function.21

Conclusions
Our results demonstrated that valve sparing aortic root reimplantation can be recommended for all patients presenting with an aortic root aneurysm and normal leaflets regardless of the aortic root diameter. Low perioperative morbidity and mortality in combination with a stable postoperative valve function encourage the use of this technique. However, final judgment on long-term durability in patients with an preoperative aortic root diameter exceeding 60 mm require further studies. Despite our limited experience with patients presenting with systemic inflammatory diseases we feel that this might be a contraindication for this type of surgery.

References
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