Preoperative aortic root geometry and postoperative cusp configuration primarily determine long-term outcome after valve-preserving aortic root repair

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Objective: Technical controversies exist in valve-preserving aortic root replacement. We sought to determine predictors of long-term stability of the aortic valve.

Methods: A total of 430 patients (aged 57 ± 15 years, 323 male) underwent valve-preserving aortic root surgery (remodeling in 401, reimplantation in 29) between 1995 and 2009 and were followed echocardiographically. Factors influencing late recurrence of aortic valve regurgitation grade II or greater ($n = 45$) or need for reoperation on the aortic valve ($n = 25$) were analyzed.

Results: Early mortality was 2.8% (1.9% for elective cases), and actuarial survival at 10 years was $83.5\% \pm 2.4\%$. Ten-year freedom from aortic valve regurgitation grade II or greater was $85.0\% \pm 2.5\%$. Preoperative aortoventricular junction diameter greater than 28 mm and postoperative effective height of the aortic cusp less than 9 mm were identified as significant predictors for late aortic valve regurgitation grade II or greater in multivariate analysis (both $P < .001$). Ten-year freedom from reoperation on the aortic valve was $89.3\% \pm 2.5\%$. Preoperative aortoventricular junction diameter greater than 28 mm ($P < .001$), use of pericardial patch ($P = .022$), and effective height of the aortic cusp less than 9 mm ($P = .049$) were identified as significant predictors for reoperation in multivariate analysis. Operative technique (remodeling, reimplantation), Marfan syndrome, bicuspid valve anatomy, concomitant central cusp plication, size of prosthesis used, and acute dissection were not associated with an increased risk of late aortic valve regurgitation grade II or greater or reoperation. In patients with preoperative aortoventricular junction diameter greater than 28 mm ($n = 94$), the addition of central cusp plication significantly improved freedom from aortic valve regurgitation grade II or greater ($P = .006$) regardless of root procedures (remodeling, $P = .011$; reimplantation, $P = .053$).

Conclusions: Long-term stability of valve-preserving aortic root replacement was influenced not by the technique of root repair but by the preoperative aortic root geometry and postoperative cusp configuration. (J Thorac Cardiovasc Surg 2012;143:1389-95)

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Since the introduction of valve-preserving aortic root replacement as root remodeling¹ or aortic valve reimplantation,² this type of surgery has received widespread attention in the last 2 decades. Both original techniques are used in addition to some modifications. Currently, the

general trend is to prefer aortic valve reimplantation based on long-term results.³ On the other hand, we have demonstrated that aortic root remodeling provides more physiologic hemodynamics, preserves near-natural root morphology,⁴⁻⁶ and requires less cardiac ischemic time.⁷ We have performed aortic valve reimplantation only in selected patients with a large aortoventricular junction (AVJ) (>29 mm) or Marfan syndrome.

Limited long-term results have been published for both forms of valve-preserving aortic root replacement,^{3,8} and little is known of the predictors of aortic valve durability. In previous publications, the preoperative size of the aortic root,^{9,10} the severity of preoperative aortic valve regurgitation (AR),¹¹ or the use of root remodeling³ has been found to be associated with an increased likelihood of recurrent AR or reoperation within the first decade.

For 15 years we have performed valve-sparing aortic root repair using both forms of valve preservation with a consistent technique. With an experience comprising more than 400 patients and follow-up reaching 15 years, we sought

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Abbreviations and Acronyms

AR	= aortic valve regurgitation
AVJ	= aortoventricular junction
BAV	= bicuspid aortic valve
CPB	= cardiopulmonary bypass
PTFE	= polytetrafluoroethylene
STJ	= sinotubular junction

to determine the predictors of long-term stability of the aortic valve.

MATERIALS AND METHODS

Between October 1995 and March 2009, we performed valve-preserving aortic root repair in 430 patients (232 male) with a mean age of 57 ± 15 years. The underlying aortic cause for elective operation was degenerative aortic aneurysm in 355 patients and chronic type A aortic dissection in 14 patients. Sixty-one patients (14.2%) underwent emergency operation for acute type A dissection. Marfan syndrome was present in 24 patients (5.6%). Fifteen patients (3.5%) had undergone previous cardiac/aortic surgery via a median sternotomy (coronary artery bypass grafting in 6, mitral valve repair in 3, aortic valve repair in 2, replacement of the ascending aorta in 2, other methods in 2). Preoperative mean New York Heart Association functional class was 2.3 ± 1.1 . Preoperative mean AR grade was 2.5 ± 0.7 , and 128 patients (29.8%) had bicuspid aortic valve (BAV) anatomy.

Choice of Root Procedure

After induction of anesthesia, all patients underwent transesophageal echocardiography (ATL HDI-3000, Philips Ultrasound, Bothell, Wash; Sequoia 256, Acuson, Mountain View, Calif). Since October 2005, the height difference between the central coaptation of cusp margin and the nadir of these sinuses or aortic insertion (effective height) was measured.^{12,13} The mean diameters of the AVJ, sinotubular junction (STJ), and sinus were measured (27 ± 2 , 42 ± 19 , and 56 ± 6 mm, respectively).

In general, no root repair was undertaken when the sinus diameter was less than 43 mm (BAV) to 45 mm (tricuspid valve). For more pronounced dilation of the root (sinus diameter > 43 –45 mm), aortic root remodeling was performed. If root enlargement was accompanied by dilation of the AVJ (> 29 mm), the aortic root was more aggressively treated by the reimplantation technique. Patients with BAV were preferably assigned to remodeling, and patients with Marfan syndrome initially underwent operation by valve reimplantation.

Anesthesia and Operative Technique

All patients received general anesthesia using standard continuous intravenous administration of propofol and sufentanil. Topical cooling of the head was used in addition to hypothermic circulatory arrest for arch replacement.

Our routine technique of valve-sparing aortic root repair has been described in detail.⁷ Briefly, cardiopulmonary bypass (CPB) was established with an aortic cannula placed in the arch and a single venous cannula. For patients with acute aortic dissection, a femoral artery was used for arterial inflow until 2001; thereafter, the right axillary artery was used. Blood cardioplegia was administered directly into the coronary ostia. In patients with extension of the aneurysm into the aortic arch, partial or total arch replacement was performed under deep hypothermic circulatory arrest with a nasopharyngeal temperature of $18^\circ\text{C} \pm 1^\circ\text{C}$. In acute type A aortic dissection, we performed partial arch replacement unless a complex entry was found in the aortic arch.

For aortic root remodeling, all 3 sinuses were excised and a Dacron graft was chosen with a similar diameter of the native AVJ, also taking the size of the patient into consideration. As a result, we selected a 26-mm graft in the majority of cases, which is generally smaller than those used at other institutions^{8,14} (Table E1). Three tongues were created, and the graft was sutured into the aortic root close to the cusp insertion lines. Care was taken to preserve the maximum height of the commissures.

For aortic valve reimplantation, the sinuses were resected and the aortic root was mobilized to the level of the AVJ. Non-pledgeted mattress sutures were placed through the root remnants at the level of the AVJ and passed through the end of a vascular graft. The remnants of aortic wall were fixed inside a graft by a continuous suture placing the commissures at maximal height. A 28-mm prosthesis was most frequently used ($n = 15$), followed by 26-mm ($n = 10$) and 30-mm ($n = 4$) prostheses.

After completion of root replacement, the aortic cusps were assessed carefully. Cusp prolapse was corrected by central plication of the free margin using single 5-0 or 6-0 polypropylene suture (Prolene; Ethicon, Inc, Hamburg, Germany). Before October 2005, inadequate height of a cusp margin relative to the others was taken as an indicator of prolapse; thereafter, an effective height of 9 to 10 mm was attempted in each cusp.^{12,13} Other cusp pathologies, such as restriction, congenital fenestration, or endocarditis lesions, were corrected by glutaraldehyde-soaked pericardial patches. BAVs were frequently repaired with triangular resection and readaptation of the fused cusps. The coronary ostia were always reimplanted using the button-technique. Intraoperative transesophageal echocardiography was performed after discontinuation of CPB to measure effective height and diameters of AVJ, STJ, and sinus (10.0 ± 1.1 mm, 25 ± 2 mm, 27 ± 2 mm, and 30 ± 2 mm, respectively).

All patients were followed clinically and echocardiographically and last seen between March and November 2010, with a mean follow-up time of 76 ± 45 months (12–181 months). The factors influencing survival, late occurrence of AR grade II or greater, and reoperation on the aortic valve were analyzed using the Cox proportional hazards model.

Statistical Analysis

Statistical analysis was performed using the StatView 5.0 program (SAS Institute Inc, Cary, NC) or Statistical Program for Social Sciences for Windows version 17.0 (SPSS Inc, Chicago, Ill). All values were expressed as mean $\pm$ standard deviation, and data from the Kaplan–Meier curves were expressed as mean $\pm$ standard error. Kaplan–Meier curves were transected at 12 years because of small number of patients at risk thereafter and compared using the log-rank test. Factors listed in Appendix 1 were entered into the analysis of predictors for late death and freedom from AR or reoperation. For freedom from AR or reoperation, a P value less than .20 in the univariate analysis was defined for selecting variables for entry into the multivariate analysis in the Cox proportional hazards model, whereas a P value less than .05 was used for late death. In the Cox proportional hazards model, all missing values were optimally substituted using multiple imputation methods.

RESULTS

According to previously published criteria,⁷ 401 patients (93.3%) underwent aortic root remodeling and 29 patients (6.7%) required aortic valve reimplantation. Cusp repair was performed in 315 patients (73.3%); the majority of repairs were central cusp plication ($n = 287$, 66.7%), followed by triangular resection ($n = 57$, 13.3%), cusp augmentation or closure of a fenestration with a pericardial patch ($n = 34$, 7.9%), subcommissural Cabrol sutures ($n = 11$, 2.6%), and Trusler sutures ($n = 3$, 0.7%). Subcommissural Cabrol sutures were used predominantly in

patients with bicuspid valve anatomy ($n = 8$). Concomitant cardiac/aortic operations were necessary in 228 patients (53.0%), most of which were aortic arch replacement ($n = 160$, 37.2%, 27 total arch replacements and 133 partial arch replacements), followed by coronary artery bypass grafting ($n = 83$, 19.3%), electroablation of the left atrium ($n = 18$, 4.2%), mitral valve repair ($n = 15$, 3.5%), and closure of persistent foramen ovale ($n = 8$, 1.9%).

Mean CPB time, aortic crossclamping time, and hypothermic circulatory arrest times were 116 ± 38 minutes, 84 ± 21 minutes, and 14 ± 9 minutes ($n = 160$), respectively. For aortic root remodeling, aortic crossclamping time was significantly shorter than for aortic valve reimplantation: 82 ± 19 minutes versus 112 ± 24 minutes for all patients and 73 ± 12 minutes versus 104 ± 16 minutes for isolated procedures ($P < .001$ each).

Survival

Twelve patients died within 30 days after surgery, for an early mortality of 2.8%. Mortality was 1.9% (7/369) after elective operations and 8.2% (5/61) for emergency procedures ($P = .006$). The causes of 12 early deaths were cardiac ($n = 4$), visceral ischemia/malperfusion ($n = 4$), stroke/subarachnoid bleeding ($n = 3$), and acute pulmonary embolism ($n = 1$). There were 38 late deaths, none of them cardiac. Actuarial survivals at 5 and 10 years were $90.5\% \pm 1.6\%$ and $83.5\% \pm 2.4\%$, respectively. Among 14 significant predictors in univariate analysis for late death, age ($P < .001$), acute aortic dissection ($P < .001$), history of cardiac/aortic surgery ($P = .001$), and body surface area ($P = .003$) were significant in multivariate analysis (Table E2).

Aortic Valve Regurgitation

AR grade II or greater developed in 43 patients during follow-up. Overall actuarial freedom from AR grade II or

greater at 5 and 10 years was $90.2\% \pm 1.6\%$ and $85.0\% \pm 2.5\%$, respectively (Figure 1, A). In univariate analysis, AVJ diameter greater than 28 mm ($P < .001$), effective height less than 9 mm ($P < .001$), and STJ diameter ($P = .025$) proved to be significant predictors of late AR grade II or greater. Multivariate analysis identified AVJ diameter greater than 28 mm and effective height less than 9 mm as significant predictors of late AR grade II or greater (both $P < .001$) (Table 1). Actuarial freedom from AR grade II or greater at 10 years was $86.6\% \pm 3.3\%$ in patients with an effective height of 9 mm or more and $76.3\% \pm 6.6\%$ in patients with an effective height less than 9 mm ($P = .006$; Figure 1, B). Actuarial freedom from AR grade II or greater at 10 years was $88.9\% \pm 2.5\%$ in patients with AVJ diameter 28 mm or less and $69.4\% \pm 7.5\%$ in patients with AVJ diameter greater than 28 mm ($P < .001$).

Reoperation

Twenty-five patients required reoperation on the aortic valve for recurrent AR ($n = 21$), infective endocarditis ($n = 3$), or aortic valve stenosis ($n = 1$). The major morphologic causes of recurrent AR were persistent or progressive cusp prolapse ($n = 10$), followed by suture dehiscence ($n = 6$; pericardial patch in 3, triangular resection in 2, Trusler suture in 1), cusp retraction ($n = 3$), and commissural detachment after reimplantation for acute dissection ($n = 2$). Overall actuarial freedom from reoperation on the aortic valve at 5 and 10 years was $95.7\% \pm 1.1\%$ and $89.3\% \pm 2.5\%$, respectively (Figure 2, A). AVJ diameter greater than 28 mm ($P < .001$), use of pericardial patch ($P = .022$), and effective height of the aortic cusp less than 9 mm ($P = .049$) proved to be significant predictors of reoperation in multivariate analysis (Table 1). Patients with AVJ diameter greater than 28 mm ($n = 94$) showed significantly reduced freedom from reoperation on the aortic valve at 10 years ($63.0\% \pm 10.3\%$) when compared with

FIGURE 1. A, Freedom from late AR grade II or greater in all patients. B, Freedom from late AR grade II or greater stratified by postoperative effective height less than 9 mm (bold line) or greater (thin line). eH, Effective height.

TABLE 1. Predictors of late aortic valve stability

	Univariate <i>P</i> value	Multivariate <i>P</i> value	HR	95% CI
AR grade $\geq$ II				
AVJ diameter > 28 mm	$<.001$	$<.001$	3.326	1.833-6.036
eH < 9 mm	$<.001$	$<.001$	3.354	1.857-6.060
STJ diameter	.025	.563		
Use of pericardial patch	.068	.071		
Concomitant CABG	.142	.177		
Reoperation				
AVJ diameter > 28 mm	$<.001$	$<.001$	5.076	2.281-11.300
Use of pericardial patch	.005	.022	3.815	1.208-12.048
eH < 9 mm	.042	.049	2.272	1.002-5.152
Body height	.115	.505		
Operative procedure	.177	.986		
Use of cusp plication	.188	.303		

Predictors of recurrent AR grade II or greater or reoperation on the aortic valve. HR, Hazard ratio; CI, confidential interval; eH, effective height; CABG, coronary artery bypass grafting.

those with smaller AVJ diameter ($n = 336$, $95.6\% \pm 1.5\%$) ($P < .001$, Figure 2, B).

Subgroup Analysis

Remodeling or reimplantation. The operative method, such as remodeling or reimplantation, did not affect late AR or reoperation. Freedom from recurrent AR at 10 years was $86.6\% \pm 2.3\%$ after remodeling and $78.4\% \pm 8.9\%$ after reimplantation ($P = .432$). Freedom from reoperation on the aortic valve at 10 years was $91.9\% \pm 2.1\%$ after remodeling and $79.6\% \pm 9.3\%$ after reimplantation ($P = .177$) (Figure 3, A). This is the case also in the subanalysis among patients with AVJ diameter greater than 28 mm ($n = 94$). Ten-year freedom from recurrent AR was $66.9\% \pm 10.3\%$ after remodeling and $76.0\% \pm 10.9\%$ after reimplantation in this cohort ($P = .253$). Freedom from reoperation on the aortic valve at 10 years was $68.9\% \pm 12.0\%$

after remodeling and $63.2\% \pm 15.6\%$ after reimplantation in this cohort ($P = .508$).

Large aortic root. In the analysis of patients with AVJ diameter greater than 28 mm ($n = 94$), concomitant central cusp plication improved late aortic valve stability significantly (10-year freedom from recurrent AR, $79.0\% \pm 8.3\%$ vs $53.4\% \pm 11.1\%$; $P = .006$) even though the reoperation rate was not significantly affected (10-year freedom from reoperation, $71.5\% \pm 14.1\%$ vs $58.2\% \pm 12.2\%$; $P = .234$) (Figure 3, B). This is also true in both aortic root procedures for patients with a large aortic root (Figure 4). After remodeling, 10-year freedom from recurrent AR was $69.2\% \pm 13.7\%$ with concomitant central cusp plication, whereas it significantly decreased to $55.8\% \pm 12.6\%$ without concomitant central cusp plication ($P = .011$; Figure 4, A). After reimplantation, no recurrent AR was observed up to 10 years with concomitant central cusp plication; on the other hand, 10-year freedom from recurrent AR was only $58.3\% \pm 16.1\%$ without concomitant central cusp plication, although the difference was due to chance ($P = .053$; Figure 4, B). We found no significant differences in freedom from recurrent AR between the 2 root procedures in this cohort (with central cusp plication, $P = .536$; without central cusp plication, $P = .178$). In addition, in patients with AVJ diameter greater than 28 mm, we found no significant differences in late valve stability between patients with bicuspid and tricuspid anatomy (AR, $P = .987$; reoperation, $P = .072$).

Effective height. A difference of valve stability between before and after the introduction of effective height concept (October 2005; $n = 263$ and 167 , respectively) was not found significant, even though the duration of follow-up of the later group was relatively short (maximum 62 months). Five-year freedom from reoperation on the aortic valve was $95.6\% \pm 1.3\%$ before the introduction of effective height concept and $95.3\% \pm 2.3\%$ thereafter ($P = .823$).

FIGURE 2. A, Freedom from reoperation on the aortic valve of all patients. B, Freedom from reoperation on the aortic valve stratified by AVJ diameter greater than 28 mm (bold line) or less (thin line).

FIGURE 3. A and B, Freedom from reoperation of patients who underwent remodeling (thin line) or reimplantation (bold line).

Size of prosthesis. The size of the vascular graft had no influence on 10-year freedom from recurrent AR or reoperation on the aortic valve. After root remodeling, actuarial freedom from recurrent AR or reoperation at 10 years in patients with a 22- or 24-mm graft was $86.6\% \pm 3.3\%$ and $94.9\% \pm 2.1\%$, respectively, whereas those with a 26- or 28-mm graft was $87.2\% \pm 3.0\%$ and $88.7\% \pm 3.8\%$, respectively ($P = .989$ and $P = .2695$). For reimplantation, a 26-mm prosthesis was selected for patients with a smaller AVJ (26.8 ± 3.4 mm) than those with a 28- to 30-mm prosthesis (31.4 ± 3.2 mm; $P = .007$). Of 10 patients who underwent reimplantation with a 26-mm prosthesis, 3 patients underwent reoperation on the aortic valve. The causes of reoperation were AR due to cusp retraction, endocarditis, and commissural detachment after acute dissection in 1 each; only the reoperation in the first patient could be related to small graft size. In the other 19 patients with a 28- or 30-mm prosthesis, 2 underwent reoperation on the aortic valve for endocarditis or commissural detachment after acute dissection. Actuarial freedom from recurrent AR or reoperation at 10 years was $75.0\% \pm 15.8\%$ and $72.9\% \pm 16.5\%$ with a 26-mm prosthesis and $70.9\% \pm 13.0\%$ and $85.0\% \pm$

10.2% with a 28- or 30-mm prosthesis, respectively ($P = .895$ and $P = .398$).

Other Factors

As analyzed by the Cox proportional hazards model (Appendix 1), Marfan syndrome, BAV morphology, use of central cusp plication, and acute aortic dissection type A did not affect late aortic valve stability.

DISCUSSION

For the past 2 decades, the concept of valve-preserving root replacement has been increasingly applied to patients with aortic root aneurysm. Differing data have been published on long-term valve stability after remodeling or valve reimplantation.^{3,8,14,15} David and colleagues³ demonstrated inferior freedom from moderate or severe AR at 10 years in the remodeling group compared with the reimplantation group, although freedom from reoperation on the aortic valve was similar.³ Other reports showed similar freedom from AR grade greater than II and reoperation at 5 years between the 2 operative strategies.^{14,15}

We have applied both techniques, and our data showed that the choice of root procedure did not predict long-term

FIGURE 4. Freedom from late AR grade II or greater of patients with AVJ diameter greater than 28 mm ($n = 94$). A, Stratified by with concomitant cusp repair (thin line) or without (bold line). B, Stratified by the choice of procedure (remodeling: solid line, reimplantation: dotted line) and with concomitant cusp repair (thin line) or without (bold line).

valve stability. These findings confirmed our earlier assumption that root remodeling results in stable aortic valve function, at least if the AVJ is not extremely dilated. One reason to prefer remodeling has been the consistently shorter myocardial ischemic time compared with reimplantation. In addition, remodeling obviates some of the extensive root mobilization that may be anatomically difficult if a relevant height discrepancy between the basal ring and the AVJ is encountered ("paper-thin right coronary sinus wall"). Furthermore, we have found that aortic root remodeling provides better hemodynamics and cusp motion *in vitro*.^{4,5} A potential disadvantage may be a progressive dilatation of the AVJ, which we have not observed. Lower transvalvular gradients have been demonstrated not only *in vitro*⁴ but also clinically^{9,14} after the remodeling technique compared with reimplantation. Hanke and colleagues¹⁰ demonstrated that a smaller preoperative annulus increased the likelihood of later development of AR after reimplantation. For these reasons, root remodeling has become our preferred approach, and in the last few years we have even extended its use to individuals with Marfan syndrome or a dilated AVJ. David and colleagues¹⁶ also recently recommended that the remodeling technique should be reserved for older patients with a normal annulus.

For some years, we had the impression that reimplantation resulted in inferior valve stability. The current analysis clearly shows that this is not the case, but rather preoperative aortic root geometry and postoperative cusp configuration determine long-term function of the aortic valve. Our data thus do not specifically indicate that the functional results of reimplantation are inferior to remodeling. Graft size in reimplantation had no obvious effect on durability, even though numbers were small. It remains to be seen whether more recent modifications of valve reimplantation can improve long-term aortic valve function. An AVJ diameter greater than 28 mm proved to be the strongest predictor for reoperation on the aortic valve, which seems consistent with other findings.^{9,10} This was true for both forms of root replacement and was thus apparently independent of the stabilization of the AVJ as part of valve reimplantation.

It is unclear whether the suboptimal valve stability observed in some patients was related to the presence of dilatation of the AVJ or determined primarily by cusp configuration, which we also found through the correlation of aortic valve function and effective height. Patients with a large AVJ also had the largest preoperative aortic root diameters. They thus undergo the greatest diameter reduction of the root and are most prone to iatrogenic prolapse.^{17,18} The fact that the addition of central cusp plication in part neutralized the negative effect of the large AVJ may support the hypothesis of induced prolapse.

The question remains whether the AVJ should be addressed separately and how it should be done. As an alternative to reimplantation, a subvalvular circular annuloplasty

using a polytetrafluoroethylene (PTFE) ring combined with a remodeling technique was performed by Kazui and associates,¹⁹ who showed favorable midterm results. Svensson and colleagues²⁰ proposed a modification of the remodeling procedure with placement of a subannular PTFE suture tied around a Hegar dilator. A multicenter study of subvalvular external aortic annuloplasty using an expansible aortic ring is currently being performed in west Europe²¹; thus, mid- or long-term data are not available. There is currently no consensus when and how to normalize the aortoventricular diameter. In addition, there are no systematic data that define the effect of reduction of the AVJ on cusp configuration.

In our series, persistent or recurrent cusp prolapse was the most important reason for reoperation after aortic valve preservation. Complete correction of preexistent or induced valve prolapse at the initial operation seems to play a key role to achieve good long-term results. The application of the effective height concept^{12,13} has facilitated reproducible cusp repair by providing a predictable indicator of near-normal cusp configuration.²² In 75.5% of patients with a bicuspid valve cusp and 32.6% of patients with a tricuspid valve cusp, the procedures involved all cusps. In line with other findings,¹⁸ a postoperative effective height of less than 9 mm had a significant negative effect on both late AR and reoperation. A beneficial effect of central cusp plication on late AR became evident in the patients with a large AVJ, whereas the choice of procedure did not.

Although our data emphasize the safety and importance of cusp repair, they do not allow conclusions regarding the best technique. Central plication of the free margin of the nodulus of Arantius using a single polypropylene suture, shortening using continuous PTFE suture along the free margin, and triangular resection of redundant cusp tissue have been proposed.²³ We have consistently applied central plication as our first choice because of the known stress distribution in the cusp.²⁴ In addition, central plication with single sutures allows stepwise length reduction or removal of sutures in case of overcorrection.

The results of the current analysis should be interpreted carefully, because this is a retrospective study of consecutive patients and not a randomized study. The constant participation of a single surgeon (HJS) has minimized differences in surgical technique, but technical modifications were made over time. Before 2005, the definition of cusp configuration was more subjective by just comparing the relative position of the free cusp margins, and generalized prolapse may have been overlooked. Only after application of our effective height concept since October 2005,^{12,13} additional cusp repair maneuvers became more systematic and reproducible. Effective height, on the other hand, not only is influenced by cusp prolapse but also may be reduced by cusp restriction.

Second, the number of patients undergoing aortic valve reimplantation was small because of our differential choice

of procedures. Most of these procedures were performed before introduction of the effective height concept. Thus, a randomized study of the 2 procedures for patients with enlarged AVJ and consistent cusp management would be required to more objectively assess their relative importance.

CONCLUSIONS

Long-term stability of valve-preserving aortic root repair is influenced less by technique used but by preoperative aortic root size and postoperative cusp configuration. It remains to be shown whether the application of standardized concepts that normalizes cusp configuration will improve aortic valve stability in the second postoperative decade.

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APPENDIX 1. Factors entered into the analysis of predictors for late death and freedom from recurrent aortic valve regurgitation II or greater or reoperation

Age
Gender
Body height
Body weight
Body surface area
Sinus rhythm
Left ventricular end-diastolic diameter
Left ventricular end-systolic diameter
Left ventricular ejection fraction
Preoperative AR
Ascending aortic diameter
Ischemic heart disease
Preoperative New York Heart Association functional class
Acute type A aortic dissection
Marfan syndrome
BAV
Preoperative shock
History of cardiac/aortic surgery via a median sternotomy
Prosthesis size
AVJ diameter > 28 mm
STJ diameter
Postoperative effective height < 9 mm
Operative method (remodeling or reimplantation)
Use of central cusp plication
Use of Trusler suture
Use of triangular resection
Use of pericardial patch
Use of at least 1 cusp repair
Concomitant aortic arch replacement (partial and total)
Concomitant coronary artery bypass grafting
Era after October 2005

TABLE E1. Prosthesis used for remodeling technique

Prosthesis	No.	Height (cm)	Weight (kg)	BSA (m ²)
22 mm	12	169.0 ± 9.4	73.0 ± 14.9	1.84 ± 0.22
24 mm	129	172.3 ± 9.4	78.1 ± 15.0	1.93 ± 0.22
26 mm	244	176.6 ± 8.7	84.4 ± 15.7	2.03 ± 0.22
28 mm	17	177.5 ± 5.8	85.4 ± 17.2	2.05 ± 0.22
Total	401	175.1 ± 9.1	82.2 ± 15.9	1.99 ± 0.23

Correlation between the size of prosthesis used for remodeling technique and the BSA of patients. *BSA*, Body surface area.

TABLE E2. Predictors of survival

	Univariate	Multivariate	HR	95% CI
Age	<0.001	<0.001	1.051	1.024–1.078
Acute aortic dissection	<0.001	<0.001	3.636	1.898–6.962
History of cardiac/aortic surgery	0.018	0.001	5.630	1.950–16.259
Body surface area	0.001	0.003	0.137	0.036–0.519
Aortic arch involvement	<0.001	0.058	2.168	0.973–4.830
NYHA class	<0.001	0.078		
Body height	<0.001	0.556		
Preoperative shock	<0.001	0.601		
All cusp repair	<0.001	0.309		
Use of cusp plication	<0.001	0.604		
BAV	<0.001	0.257		
Gender	<0.001	0.767		
Body weight	0.010	0.163		
Left ventricle ejection fraction	0.040	0.978		

Predictors of survival. *HR*, Hazard ratio; *CI*, confidential interval; *NYHA*, New York Heart Association.