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Aortic Valve Repair: The Functional Approach to Leaflet Prolapse and Valve-Sparing Surgery

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Background. **Combined aortic valve repair and aortic valve–sparing surgery requires an approach determined by the leaflets and aortic root anatomy.**

Methods. **Among patients referred for aortic root aneurysm, 114 patients underwent an aortic valve–sparing procedure in which a reimplantation or remodelling technique was used. The Gelweave Valsalva prosthesis (Sulzer Vascutek, Renfrewshire, UK) was used in 45 patients. Better molding of the prosthesis on the aortic annulus was achieved by a low proximal dissection and incisions on the prosthesis to respect the anatomy of the aortoventricular junction. The reimplantation technique was used in 58%, and 62% of all patients underwent an associated leaflet procedure.**

Results. **The operative mortality rate was 1%, with a 2% immediate reoperation rate. During the mean follow-up 50 ± 35 months, 3 patients (2.6%) needed reoperation for recurrent aortic regurgitation (n = 2) or aortic stenosis (n = 1). At the end of follow-up, aortic regurgitation grade exceeding 2 had occurred in 2.6% of patients (n = 3), and 98.2% were in New York Heart Association functional class 1 or 2. Neither the early nor mid-term results showed any differences among the different surgical techniques used (reimplantation, remodeling, Valsalva prosthesis, additional leaflet repair).**

Conclusions. **A complete approach to the different components of the aortic root allows good clinical results at mid-term.**

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The interest in aortic valve repair and aortic valve–sparing surgery has been growing for more than a decade, and a few publications have reported interesting long-term results [1, 2]. The ability to avoid the insertion of a prosthesis, with its related long-term complications, by preserving the patient's aortic leaflets has promoted an increased interest in these techniques. The two main techniques reported for aortic valve–sparing surgery have been the remodelling technique [3] and the reimplantation technique [2]. These techniques restore the aortic root shape and produce a symmetrical rapprochement of the leaflets. It is not rare to observe, however, associated with the root dilatation, a leaflet prolapse, or other leaflet abnormalities that need additional correction.

In our view, the aortic root must be considered one functional unit with two borders: the aortoventricular junction (proximal), and the sinotubular junction (distal). The combination of these two limits is regarded as the functional aortic annulus (FAA), equivalent to the mitral annulus. With this in mind, the anatomy of the aortic root can be simplified to its two major components: the leaflets and the FAA. In an earlier report [4], we described the functional classification of aortic regurgitation (AR) linked to the pathophysiologic mechanism causing the regurgitation:

Type I. Normal appearing cusps with FAA dilation.

Ia: Ascending aorta dilation (starting at the sinotubular junction)
Ib: Valsalva sinuses and sinotubular junction dilation
Ic: FAA dilatation
Id: Cusp perforation

Type II. Cusp prolapse: excess of cusp tissue, or commissural disruption
Type III. Cusp retraction and thickening

Both aortic valve–sparing operations have been performed in our center, but our technique of choice has become the reimplantation technique, mainly because of its ability to provide a more effective stabilization of the aortic annulus. Our increasing understanding of aortic valve pathology has directed us toward a more functional approach to the aortic root with its two main components: the leaflets and the FAA. The aim of our technique is to maintain or restore the spatial configuration of the aortic valve by preserving or correcting the natural borders of the aortic valve and by correcting any associated leaflet pathology. This article describes our reimplantation technique and results with aortic valve–sparing surgery, with special attention on the key issue of the management of leaflet coaptation and prolapse correction.

SUPPLEMENT

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Material and Methods

From December 1995 to October 2005, 114 patients were referred for elective aortic root and ascending aorta aneurysm. The reimplantation technique was used in 66 patients (58%) and the remodeling technique in 48 (42%). An associated leaflet correction was needed in 71(62%) of these patients. We retrospectively reviewed this cohort of patients. Perioperative data were collected from hospital records. Clinical follow-up was obtained by calling the patients or their referring physicians, and echocardiographic follow-up was completed with the most recent controls performed by referring cardiologists. The study was approved by the Institutional Ethics Committee.

All cases of AR are approached through a median sternotomy, with cannulation of the aorta and the right atrium, and normothermic cardiopulmonary bypass. Depending on the extent of the aneurysm and when the situation dictates, the arterial cannulation site can be changed to the axillary or the femoral artery. Warm antegrade blood cardioplegia is given through direct cannulation of the coronary ostia. When circulatory arrest is needed, we use selective antegrade perfusion of the brachiocephalic trunk and the left carotid artery during the arrest, with a perfusion pressure of 50 mm Hg.

The Reimplantation Technique

The aorta is incised 1 cm above the commissures in a circular plane to preserve the geometry of the aortic root and to allow a better evaluation of the valve. A suture is placed at the tip of each commissure and left for the entire procedure. If a prolapse is found, it is not repaired until after the reimplantation of the leaflets to avoid over-correction or under-correction of the prolapse. It is difficult to anticipate the effect of the sparing procedure on the prolapse.

If a small perforation is found, primary closure of the defect can be performed if enough tissue is present to avoid distortion of leaflet geometry. To correct a larger defect, a pericardial patch is used. The size of the patch must be bigger than the defect to avoid tension on the suture line and deformation of the leaflet. The dissection of the aortic root at the level of the noncoronary sinus

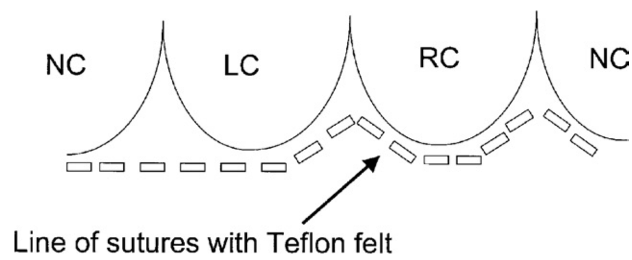

Fig 2. The proximal line of suture reinforced with Teflon felt (arrow) has to follow the external limitation of the aortic root. (NC = noncoronary; LC = left coronary leaflet; RC = right coronary leaflet.)

continues until the deepest point of implantation of the leaflet. For the left and the right coronary sinus, the dissection is extended to the level of the right ventricular outflow tract (RVOT). If the dissection is too deep at this level, there is a risk of right ventricular perforation (Fig 1). The aortic wall is cut, and a rim of tissue is left around the line of insertion of the leaflet in the sinus.

To evaluate the size of the prosthesis needed, the commissural stitches are pulled up and then brought inward until a good line of coaptation is obtained. The space between the three commissures is approximated by Hegar dilatators. The size of the prosthesis will be the size of the Hegar dilator plus 4 mm to compensate for the external position of the prosthesis.

The proximal suture line has to respect the outer limits of the aortoventricular junction (ie, RVOT at the level of the left and right coronary sinus). Sutures reinforced with Teflon (DuPont, Wilmington, DE) are used. The first suture is placed in the middle of the subcommissural triangle of the noncoronary/left coronary commissure at the level of the deepest point of implantation of the noncoronary leaflet. The rest of the sutures are placed in a horizontal plane in a clockwise fashion to the middle of the left coronary sinus, where the external limitation will require an ascending suture line. From that point until the middle of the noncoronary sinus, the suture line will

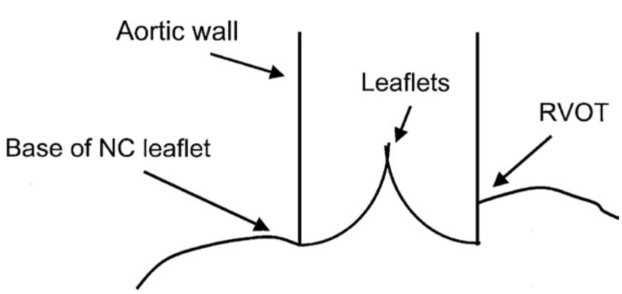

Fig 1. This schematic representation of the aortic root shows its external limitations. The dissection of the aortic wall must continue to the base of implantation of the noncoronary leaflet (NC). At the level of the left and right sinuses, the dissection is limited by the presence of the right ventricular outflow tract (RVOT). A deeper dissection at this portion is a risk for ventricular perforation.

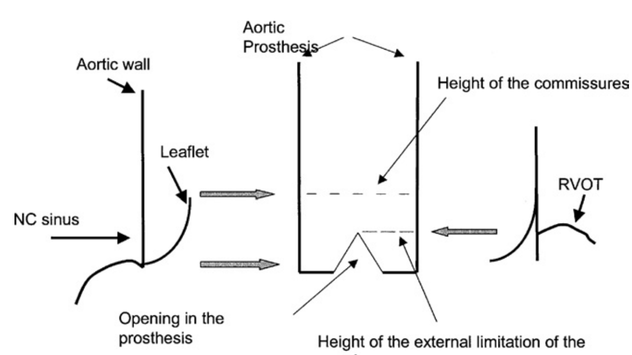

Fig 3. After measuring the height of the new sinotubular junction, the prosthesis is cut to respect the anatomy of the aortoventricular junction. (NC = noncoronary; RVOT, right ventricular outflow tract.)

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Table 1. Demographic Data

	All Patients n = 114	Reimpl n = 66 (58%)	Remodeling n = 48 (42%)	Reimpl With Valsalva Prosth Subgroup n = 45 (39%)	AV Repair Subgroup n = 71 (62%)
Preoperative					
Age (m ± SD)	52 ± 16	51 ± 15	54 ± 17	54 ± 15	51 ± 15
Gender (F/M)	25/89	11/55	14/33	8/37	8/35
Marfan disease	9	4	5	3	3
Bicuspid valve	35	24	11	14	33
Endocarditis	3	0	3	1	2
NYHA ≥3	19	9	10	11	13
AVR grade					
≤1	25	11	14	13	7
2	26	12	14	4	18
3	36	23	11	9	23
4	27	18	9	23	23
EF (m ± SD)	0.57 ± 0.11	0.57 ± 0.11	0.58 ± 0.10	0.58 ± 0.10	0.56 ± 0.11
EF 0.30–0.50	10	8	2	2	8

AV = aortic valve; AVR = aortic valve regurgitation; EF = ejection fraction; m ± SD = mean ± standard deviation; NYHA = New York Heart Association functional class; Reimpl = reimplantation.

follow the line of implantation of the leaflets; after this, the suture line will be horizontal again (Fig 2).

The prosthesis is then cut to fit the anatomy of the aortic annulus. The height of the commissures is evaluated by measuring the distance between the deepest point of implantation of the noncoronary leaflet to the tip of the left/noncoronary commissure. This value is transposed onto the prosthesis, and a mark is made around the prosthesis to mimic the new sinotubular junction. Next, the outer limits are measured at the level of the left/right coronary and right/noncoronary commissures. To obtain this value, the distance between the RVOT and

Table 2. Intraoperative and Early Postoperative Data

	All patients n = 114	Reimpl n = 66 (58%)	Remodeling n = 48 (42%)	Reimpl With Valsalva Prosth Subgroup n = 45 (39%)	AV Repair Subgroup n = 71 (62%)
Intraoperative					
A. prosth	28 ± 2	28.5 ± 1.6	26 ± 2.3	29 ± 1.4	28 ± 1.8
AV repair	71	48	23	31	71
Associated procedures	21	14	6	8	14
CABG	9	4	5	1	5
MV repair	6	4	1	4	4
PFO closure	5	5	0	2	4
TV repair	1	1	0	1	1
Second run	11	7	4	4	8
ACC (min)[a]	106 ± 27	110 ± 25	98 ± 31	113 ± 26	106 ± 23
CPB (min)[a]	129 ± 34	133 ± 28	120 ± 44	135 ± 32	128 ± 27
Postoperative					
OR mortality	1	0	1	0	0
Reop. bleeding	16	9	7	6	10
Early AV reop.	2	1	1	1	1
Stroke	1	1	0	0	0
Pneumonia	2	2	0	1	1
Renal failure	3	3	0	2	2
Hospital LOS (days)[a]	10 ± 4	10 ± 5	9 ± 4	9 ± 4	10 ± 5

[a] Data are presented as means ± standard deviation.

ACC = aortic cross-clamp time; A. prosth = aortic prosthesis size; AV = aortic valve; CABG = coronary artery bypass grafting; CPB = cardiopulmonary bypass time; LOS = length of stay; MV = mitral valve; OR = operative; Reimpl = reimplantation; TV = tricuspid valve.

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the tip of each commissure is measured. This will give the distance between the sinotubular junction and the highest point of the outer limits of the two remaining commissures. Each measurement is marked on the prosthesis at the level of the corresponding commissure, starting from the new sinotubular junction and going toward the proximal end of the graft.

The prosthesis will be cut from the proximal end of the graft, going toward the distal end, until that level (Fig 3). The prosthesis is then slightly beveled on each side to mimic the shape of the aortic root. The sutures are placed on the prosthesis, respecting their line of implantation on the annulus and their spacing. The commissural sutures are pulled up when the suture is tied to ensure even placement of the prosthesis on the annulus.

Each commissure is then fixed at the level of the new sinotubular junction, and a running suture is used to reimplant the leaflet inside the prosthesis. The coaptation line is then evaluated. If a residual or new prolapse is found, it is treated by free-edge plication, with one or two simple sutures placed from one side of the nodule of Arantius to the other side and tied, or it is shortened with a running Gore-Tex suture (W.L. Gore & Associates, Flagstaff, AZ) to adjust the coaptation height. The coronary ostia are anastomosed in the usual fashion.

After weaning from cardiopulmonary bypass, a complete transesophageal echocardiogram is performed to evaluate the valve function. The height of the line of coaptation of the leaflets should be well above the plane of the aortic annulus to avoid recurrence of AR. If a significant eccentric regurgitant jet is found, residual prolapse should be suspected, and a second run should be performed to correct the situation.

Results

From December 1995 to October 2005, 114 patients (mean age, 54 ± 16 years) were referred for elective aortic aneurysm, and 19 (18%) were in New York Heart Association (NYHA) class III or higher. The preoperative demographic data are listed in Table 1.

Operative Data

The operative data are summarized in Table 2. The reimplantation technique was used in 66 patients (58%) and the remodeling technique in 48 (42%). Forty-five (39%) patients in the reimplantation group received a Gelweave Valsalva prosthesis (Sulzer Vascutek, Renfrewshire, UK). Seventy-one patients (62%) needed an associated leaflet correction. Techniques used to correct the leaflets pathologies were subcommissural annuloplasty stitches in 32 patients, free edge suspension/ reinforcement with Gore-Tex (CV7) in 33, triangular resection with direct suture in 17 and with patch insertion in 8, and free edge plication in 13. Associated procedures were CABG (8%), mitral valve repair (5%), and tricuspid valve repair (1%). Mean aortic cross-clamp and cardiopulmonary bypass times were 106 ± 27 and 129 ± 34 minutes. A second pump-run was required in 11 (9.6%) patients to correct residual AR.

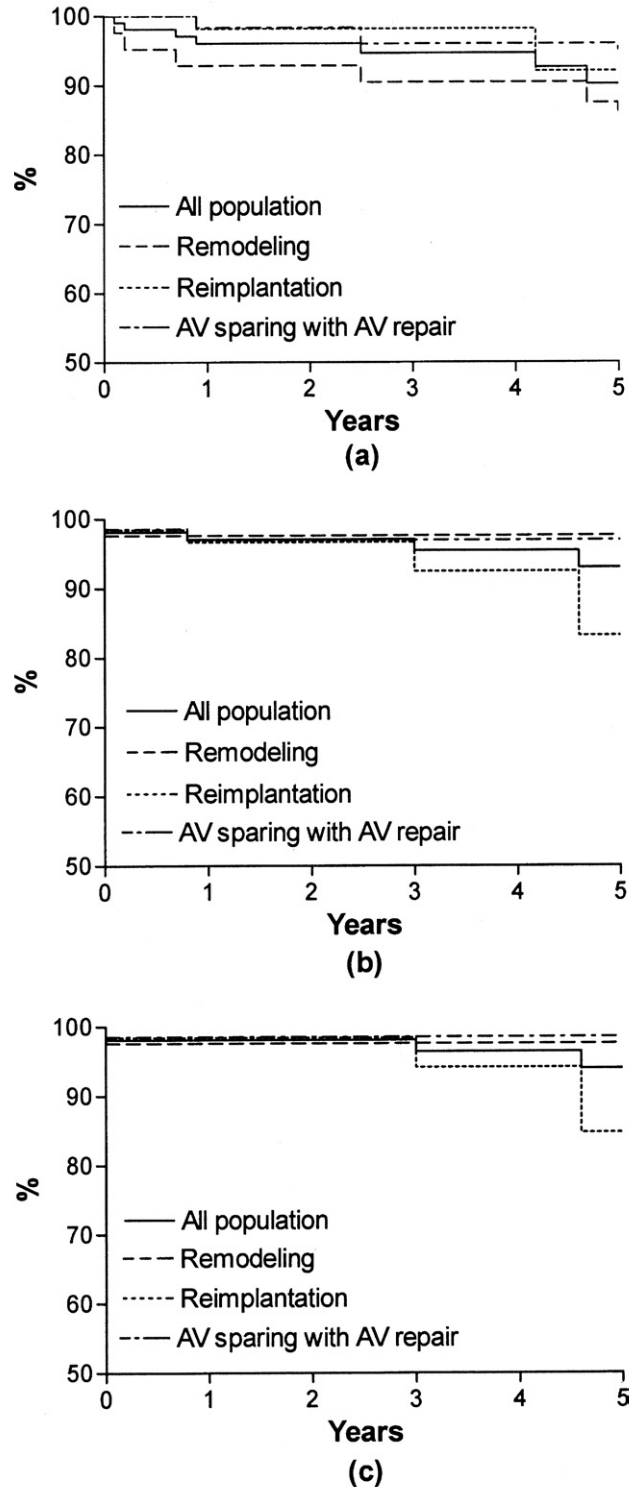

Fig 4. (a) Kaplan-Meier overall actuarial survival. (b) Kaplan-Meier curve for freedom from recurrence of aortic regurgitation exceeding grade 2 or stenosis (including early and late recurrences). (c) Kaplan-Meier curve for freedom from mitral valve reoperation (including early and late reoperations). (Solid line, all population; dashed line, remodeling; dotted line, reimplantation, dash-dot line, aortic valve [AV] sparing with AV repair.)

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Early Postoperative Results

The early postoperative results are summarized in Table 2. One patient (1%) died from aspiration pneumonia. There were no perioperative myocardial infarctions or strokes. Reexploration for bleeding was needed in 14%. Two (1.7%) early aortic valve reoperations were also needed. One patient presented recurrent regurgitation after bicuspid valve repair and reimplantation procedure and underwent a Ross operation on postoperative day 10. Suture disruption of an autologous tricuspid valve patch implanted on a cusp perforation occurred in a second patient and an aortic valve re-repair was performed on postoperative day 11.

Follow-Up Data

Mean follow-up time was 50 ± 35 months and was 93% complete. There were 10 late deaths, four of which were cardiac related. Only 2 patients (1.7%) were in NYHA class II or higher. Three patients needed a reoperation at 3, 5, and 8 years. Recurrent AR developed in 2 patients, of which 1underwent re-repair. One patient presented with aortic stenosis that required a valve replacement, and a third patient also underwent a valve replacement.

At the time of follow-up, 80.4% (74/92 survivors, not lost from follow-up, without aortic valve replacement) had no or grade 1 AR, 16.3% (15/92) had grade 2 AR, and 3.2% (3/92) had a recurrence of AR exceeding grade 2. Most patients (98%) were in NYHA class I or II, and no patient presented with endocarditis during this period.

In the total cohort, 5-year overall survival was 90% ± 7.5%, freedom from AR exceeding grade 2 or stenosis was 93% ± 6.5%, and freedom from reoperation was 94% ± 6% (including early and late recurrences and reoperations). Those percentages were, respectively, 87%, 97%, and 97% in the remodeling subgroup; 92%, 83%, and 85% in the reimplantation subgroup; and 95%, 97%, and 98% in the aortic valve–sparing with aortic valve repair subgroup. There were no statically significant differences between the different techniques (remodeling versus reimplantation versus aortic valve–sparing with aortic valve repair; Fig 4).

In the Valsalva prosthesis subgroup, there was one early (tricuspid autologous patch dehiscence) and one late (severe AR recurrence) reoperation. No other recurrence of AR exceeding grade 2 was recorded during the follow-up period.

Table 3. Steps in Repair From the Mitral to the Aortic Valve

• Mitral leaflet prolapse	• Aortic leaflet prolapse
Quadrangular resection	Free-edge plication
Chordal transfer	Gore-Tex running suture
Neo-chord implantation	
• Mitral annulus dilatation	• Aortic root dilatation (FAA)
Annuloplasty	Sinotubular junction remodelling
	Sinotubular junction plasty
	Subcommissural plasty
	Reimplantation technique

FAA = functional aortic annulus.

Table 4. Surgical Approach

Type	Surgery
1a	Sinotubular junction remodelling
1b	Reimplantation or remodelling technique
1c	Sinotubular junction plasty
	Subcommissural annuloplasty
1d	Primary repair
	Patch repair
2	Leaflet free-edge plication
	Correction level of coaptation by a running suture

Comment

For more than a decade, the interest in aortic valve repair and aortic valve–sparing surgery has been growing. The avoidance of the insertion of prosthesis by preserving the patient's aortic leaflets has promoted an increased interest in these techniques. Our approach to AR has been tailored by our experience in mitral valve repair. The two functional components of the aortic root (the leaflet and the FAA) can be seen as analogous to the leaflets and the mitral annulus.

As in mitral valve repair, steps are (1) management of the leaflet and (2) stabilization of the repair by preserving or correcting the FAA (mitral annuloplasty; Table 3). The surgical technique used to correct AR will mostly depend on the preoperative assessment of the lesion causing AR (Table 4). In most cases, one or the two components of the aortic root are implicated in the pathologic phenomenon; furthermore, with long-standing AR, the FAA tends to dilate with time, even in cases of isolated leaflet prolapse. Thus, a functional annuloplasty is necessary in any valve repair for aortic regurgitation.

Transesophageal echocardiography has become the cornerstone of AR evaluation, mainly because of its ability to give a dynamic view of the aortic root. The presence of an eccentric jet of aortic regurgitation should always raise concern about associated leaflet pathology.

Different groups have reported good long-term results with the remodelling or the reimplantation technique [1–3]. Questions have been raised, however, on the long-term stability of the remodelling technique owing to the absence of aortic annulus stabilization [5, 6]. Progressive appearance of AR could be caused by dilatation of the aortic annulus that is left without support. The addition of an external aortic annuloplasty to prevent this complication has been associated with good early results, but longer follow-up is still needed [7]. Both valve-sparing techniques have been used in our experience with similar results, but in recent years we have almost exclusively used the reimplantation technique to prevent this long-term recurrence of AR.

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The main advantage of the remodelling technique is the restoration of the aortic sinuses to provide a more physiologic function of the aortic valve. The presence of sinuses of Valsalva guarantees a proper opening and a smooth closing of the valve leaflets while greatly reducing their mechanical stress. In trying to restore the anatomy the aortic root, the Gelweave Valsalva prosthesis was developed to allow the reconstruction of egg-shaped sinuses of Valsalva and a well-defined sinotubular junction independently from the surgical technique [8].

Excellent early results have been reported by different groups with this prosthesis [9, 10]. Pacini and colleagues [11] have reported satisfactory mid-term results with freedom from aortic valve replacement of 90.8% and recurrence of AR exceeding 2 of 88.7%. Our results with this prosthesis have been comparable, but a learning curb was seen, especially in the trimming of the prosthesis proximally. The long-term stabilization of the aortic annulus and the benefices of this prosthesis remain to be studied.

Risk factors for early failure of the remodelling procedure have been studied by Pethig and colleagues [12]. When analyzing possible preoperative data, surgical indication and pathology, and procedure-related risk factors in a multivariable approach, only the level of coaptation within the graft was identified as being related to the subsequent development of aortic insufficiency. Coaptation level within the tube graft resulted in a mean aortic regurgitation grade of 0.3 ± 0.5 compared with a mean grade of 2.5 ± 0.6 for a coaptation level below the prosthesis. This can be caused by a missed preoperative prolapse of one or more leaflets or can be induced during the reimplantation of the leaflets in the prosthesis. In such situations, second run is recommended to restore a normal configuration of the leaflets.

Langer and colleagues [13] and Schafers and colleagues [14] have reported excellent mid-term results with the association of a leaflet procedure with an aortic valve–sparing procedure. There were no differences in operative mortality, survival, and freedom from aortic valve replacement or recurrence of AR greater than 2 when a leaflet procedure was added. We found similar results in our experience [15]. The presence or the appearance of leaflet prolapse has to be looked for and treated to obtain good long-term results.

By using a systematic approach that is based on a functional understanding of aortic regurgitation, aortic valve–sparing surgery and leaflet correction offers a safe and durable treatment option in the management of aortic root disease. The mean issue and subsequently the key for immediate and long-term success of the valve-sparing procedure is the preservation or restoration of a valve with appropriate configuration.

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