

Valve-sparing aortic root surgery. CON: remodeling

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Abstract The two major valve-sparing root replacement procedures, aortic valve reimplantation (reimplantation) and aortic root remodeling (remodeling), have advantages and disadvantages, which are reviewed herein. The main advantage of reimplantation is the resulting annular support, and the disadvantages are the unfavorable hemodynamics and relatively long procedure time. The main advantages of remodeling are the physiological hemodynamics and decreased procedure time, and the disadvantage is the lack of annular support. With technical advances and modifications, however, the differences between these two procedures have narrowed. Application of a graft with sinuses for reimplantation improves the hemodynamics, and addition of annuloplasty to remodeling provides the necessary annular support. Nevertheless, remodeling has some advantages because less root dissection is required and the procedure time is shorter and hemodynamically favorable. Thus, remodeling may be the procedure of choice for high-risk patients (such as those with acute aortic dissection, of advanced age, with reduced ventricular function, or undergoing a concomitant operation). Remodeling may also be best for young athletes because of the hemodynamic advantage. Regardless of the advantages and disadvantages, both procedures provide excellent clinical results in terms of late valve durability. Surgeons should be familiar with both techniques and properly match patients to the appropriate treatment.

Keywords Aortic root remodeling · Aortic valve reimplantation · Valve-preserving root replacement · Aortic valve repair · Annuloplasty

Introduction

A quarter of a century has passed since the aortic root enlargement with or without aortic regurgitation (AR) met with innovative treatments: reimplantation of the aortic valve (hereinafter referred to as reimplantation) proposed by David and Feindel [1] and remodeling of the aortic root (hereinafter referred to as remodeling) advocated by Sarsam and Yacoub [2]. Valve-sparing root replacement remains viable today. Both approaches to aortic root enlargement have advantages and disadvantages, and both have evolved over time. A distinct advantage of reimplantation is robust annular stabilization, and the main disadvantage is the unfavorable hemodynamics that results from decreased root distensibility. An obvious advantage of remodeling is the physiological hemodynamics that results from preserved root distensibility, and the main disadvantage is the lack of annular stabilization. The differences between the two procedures have narrowed, however, because of two remarkable breakthroughs: creation of a graft with sinuses to improve physiological hemodynamics and annuloplasty to stabilize the annulus. Thus, David, who pioneered valve reimplantation, has stated, “After more than 2 decades of experience with these operations, we have concluded that they are not competitive procedures, but provide excellent long-term results when correctly matched to the aortic root pathology” [3]. Nonetheless, there remain some characteristic differences between the two alternatives. The aim of this review is to provide an overview of the existing advantages of remodeling over reimplantation.

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Remodeling and its technical modifications

Under the original remodeling procedure described by Sar-sam and Yacoub, the prosthesis was chosen for size simply by eyeballing to provide maximal coaptation of the cusps. A 30-mm prosthesis, which is a fairly large prosthesis, was most frequently selected. Before implantation, three tongues were created to equal at least one and a half times the height of each of the sinuses of Valsalva [4]. The tongues were sutured to the respective sinuses of Valsalva from the commissure to the nadir, and the excess prosthesis material was trimmed, with no attempt to increase the height of the commissures. Nowadays, the prosthesis selected is one size smaller (or 10% smaller) than the diameter of the ventriculo-aortic junction (VAJ) unless the root is extremely enlarged [5], or the prosthesis is selected on the basis of the patient's body surface area [6]. The prostheses most frequently used nowadays are 26–28 mm in diameter [6, 7]. Use of a tube graft allows the commissures to be brought up as high as possible [6], whereas use of a graft with sinuses requires that the commissures be fixed at the same height of the graft diameter [7].

Table 1 Characteristics of the aortic root remodeling procedure and the aortic valve reimplantation procedure

	Remodeling	Reimplantation
Procedure time	Relatively short	Relatively long
Operative technique	Technically demanding; standardized by a graft with sinuses	Reproducible
Annular stabilization	Poor; improved by annuloplasty	Excellent
Root distensibility	Preserved	Up to prosthesis
Hemodynamics	Physiological	Poor; improved by a graft with sinuses
Risk of bleeding	Relatively high	Relatively low

Table 2 Aortic cross-clamping times during aortic root remodeling and aortic valve reimplantation and the difference between them reported by institutions that perform both procedures

First author (year)	Remodeling	Reimplantation	Difference
Leyh (2002) [10]	143 ± 18 (n = 8) [100%]	157 ± 24 (n = 22) [100%]	14
Jeanmart (2007) [11]	98 ± 31 (n = 48) [0%]	110 ± 25 (n = 66) [0%]	12
Hanke (2009) [12]	138 ± 39 (n = 108) [29%]	165 ± 49 (n = 83) [42%]	27
Kunihara (2012) [13]	73 ± 12 (n = 401) [14%]	104 ± 16 (n = 29) [24%]	31
Svensson (2012) [14]	100 ± 35 (n = 72) [26% ^a]	114 ± 21 (n = 71) [15% ^b]	14
Average	91.1	123.7	32.6 ^c

Times are shown as mean ± SD minutes unless otherwise indicated

Percentages are the percentages of cases of type A acute aortic dissection

^aEmergency cases = 21%

^bEmergency cases = 3%

^c(123.7 – 91.1)

To prevent late annular expansion, many annular stabilization (annuloplasty) techniques have been tried, the most common being external suture annuloplasty [8], external adjustable ring annuloplasty [7], and internal ring annuloplasty [9], which are discussed below.

Remodeling vs. reimplantation

Characteristics of remodeling and reimplantation are summarized in Table 1, and they are compared in detail below.

Duration of the procedure

Remodeling requires a single aortic-graft suture line, whereas reimplantation requires two suture lines. Because the working space for adding a second row of sutures is quite small, this step is somewhat time consuming. In addition, remodeling with external suture annuloplasty requires surgical dissection to the level of the VAJ, whereas reimplantation requires surgical dissection to the level of the basal ring. However, remodeling with external ring annuloplasty requires the same extensive root dissection required for reimplantation. Therefore, the myocardial ischemia time is shorter for remodeling than for reimplantation unless external ring annuloplasty is performed.

Some institutions that perform both remodeling and reimplantation have reported aortic cross-clamping times for each procedure [10–15], and these times are shown in Table 2. According to these reports, remodeling required 32.6 min less aortic cross-clamping time than that required by reimplantation. Thus, even with the heterogeneity of the reported patients (in terms of concomitant operations, acute aortic dissection, and/or cusp etiology, for example) taken into account, remodeling is advantageous in terms of procedural duration. Therefore, to reduce myocardial ischemia time for high-risk patients, experts have recommended

remodeling for older patients with a normal aortic annulus [15] and for patients who have suffered acute aortic dissection [16].

Operative technique

Remodeling is technically demanding and is influenced by the decisions the surgeon makes once the procedure is begun. The surgeon must, for example, fashion the tongues of the prosthesis freehand. Thus, the tongue configuration is highly variable, and this can affect the final root configuration. In addition, the commissures should be brought up as high as possible, and for this reason, the surgeon must carefully determine the width of each stitch between the native side and the prosthesis side to create the sinus bulges. This maneuvering depends on the surgeon's skill. However, when a graft with sinuses is used, the commissure height is determined by the size of the graft, which makes the procedure reproducible. Reimplantation is somewhat more standardized. Once a prosthesis of suitable size is selected and each commissure is fixed at its optimal position, the surgeon's skill is less likely to contribute to the final result, although more advanced root dissection is required than that required for remodeling.

Annular stabilization

Annular stabilization has become an important issue. In the early days of remodeling, clinically acceptable outcomes were achieved even without annular stabilization. However, cases in which the annular dimensions were normal were generally assigned to remodeling, and the others were assigned to reimplantation. Over time, a large annulus (>28 mm in maximum diameter) emerged as a risk factor for late failure [6, 13, 17, 18], and annular stabilization took on a role of importance for successful remodeling. Initially, subcommissural annuloplasty, a simple procedure advocated by Cabrol et al., was used widely [19]. Then David et al. began stabilizing just the fibrous portion of the aortic root with a Dacron strip, a technique that became known as the "David-III technique" [20]. However, partial reduction of the annular base has since been associated with recurrence [17, 18, 21–23]. In addition, inhomogeneous plication can negatively affect cusp movement.

Circular annuloplasty is now widely practiced. Currently, there are three main clinical alternatives: external suture annuloplasty [8], external ring annuloplasty [7], and internal ring annuloplasty [9].

External suture annuloplasty is not time consuming and requires root dissection only to the level of the VAJ. Thus, the advantages of remodeling can be best maintained when

external suture annuloplasty is performed. In addition, the sutures are tied around a Hegar dilator of target diameter, which makes the postoperative annulus diameter highly predictable. The disadvantage of external suture annuloplasty is that the commissure angle cannot be changed. If, in cases of a bicuspid aortic valve (BAV), the ideal commissure angle is close to 180° at the level of the annulus, the raphe can be plicated locally [24].

External ring annuloplasty requires root dissection to the level of the basal ring. Otherwise, the ring will be implanted in a tilted position, high in the right coronary sinus area and low in the non-coronary sinus area [25]. External ring annuloplasty makes the remodeling procedure quite similar to the reimplantation procedure, and it requires more time than suture annuloplasty requires. The only difference is preservation of the interleaflet triangles, which, when reimplantation is performed, are covered by the prosthesis. When external ring annuloplasty is applied, the commissure angle can be adjusted. However, the postoperative diameter of the annulus cannot be predicted because it depends on the thickness of the interventricular muscle.

Internal ring annuloplasty does not necessitate root dissection; thus, combined with remodeling, it is an attractive alternative. However, the configuration of the annulus varies greatly among individuals, so stress placed on the annulus by a rigid ring remains a matter of concern. Indeed, relatively frequent early failures have been reported [9]. Experts have warned of the possible hazards of a rigid ring in close proximity to the delicate aortic cusps [26]. Thus, internal ring annuloplasty performed with a circular flexible ring, as described by Kawazoe et al., is an attractive option in terms of cusp coaptation at the commissure [27]. However, there is yet no long-term evidence that it is superior to the other annuloplasty methods in terms of cusp coaptation.

Root distensibility

As noted above, the greatest difference between remodeling and reimplantation is preservation of the interleaflet triangles afforded by remodeling, which is also considered one of the advantages of remodeling [28, 29]. During systole, the aorta and VAJ expand as much as 18–20 and 5–15%, respectively, whereas a vascular prosthesis expands only 3% [30–32]. In an in vitro study, approximately 9–10% annular distensibility was maintained after remodeling without annuloplasty, but only 5% was maintained after reimplantation [28]. In a clinical study comparing the Valsalva graft (with sinuses) against the tube graft, sinus distensibility 6 months after Valsalva graft implantation was 4.4%; however, that after tube graft implantation was only 1.9% [33]. Further, annular distensibility after implantation of a graft with sinuses was only 2.5–4%, did not differ from that after implantation of

a tube graft (3.5%), and was inferior to that after remodeling performed without annuloplasty (6.3%) [33, 34]. In contrast, use of an external expandable aortic ring combined with remodeling was reported to result in 4.8–9.1% annular distensibility during a median follow-up period of 19 months (up to 5 years) [29]. Similarly, 10% systolic expansion was maintained up to 2 years after implantation of an expandable external ring combined with remodeling or the Ross procedure [35]. Long-term root distensibility has been investigated in cases of remodeling with external ring annuloplasty but not in cases of remodeling with external suture annuloplasty or internal ring annuloplasty, but we anticipate such investigations and look forward to the findings.

Hemodynamics

It is widely accepted that the sinuses of Valsalva play an important role in aortic root flow dynamics, particularly in the characteristics of valve opening and closing. Both in vitro and clinical studies have shown rapid valve opening and closing velocity to be slower after remodeling than after reimplantation [34, 36, 37]; greater cusp displacement during slow closing has also been shown after remodeling [36, 37]. The difference appears to diminish when a graft with sinuses is used for reimplantation [34]. Similarly, use of a graft with sinuses has a beneficial effect on rapid valve opening and closing velocity [33, 38]. Nonetheless, these parameters remain better with remodeling: rapid valve opening and closing velocity are reported to be 27–44 and 32–34 cm/s, respectively, with remodeling [34, 37] and 36–69 and 41–48 cm/s, respectively, with reimplantation when a graft with sinuses is used [33, 34, 38]. The differences were accelerated with higher cardiac output [36].

Another concern is the transvalvular pressure gradient. Both in vitro and clinical studies have indicated that reimplantation, vs. remodeling, is associated with a higher transvalvular pressure gradient [28, 34, 37, 39], which was enhanced with increasing cardiac output [39]. This is not clinically relevant at rest, but it is relevant upon exercise, and this is important because the majority of patients undergoing valve-sparing root replacement are relatively young. Furthermore, an increased transvalvular pressure gradient has been identified as a risk factor for late failure of aortic valve repair [40].

Remodeling, in comparison to reimplantation, puts less stress on the cusps, and less energy is lost through the aortic annulus [39, 41]. However, results of clinical comparisons should carefully be interpreted because postoperative outcomes, annulus size, for example, have not been identical between patient groups. In addition, the effect of

annuloplasty on remodeling is unclear. Detailed investigation of these factors is needed.

Risk of bleeding

Reimplantation requires two suture lines, whereas only one suture line is needed for remodeling; thus, the risk of postoperative bleeding is greater when remodeling is performed. However, postoperative bleeding can be prevented under the following guidelines:

1. The remnant aortic wall should be wide (approximately 4–5 mm).
2. The prosthesis should be positioned inside the remnant aortic wall.
3. The sutures should be placed precisely along the firm cusp insertion line.
4. A slightly rigid graft should be chosen to ensure the coaptation between the remnant aortic tissue and graft.
5. Cardioplegic solution should be infused into the graft after the anastomosis is completed. This should be done to check for bleeding, and additional hemostatic sutures should be placed if necessary (adhesive glue is also an option).

With these precautions taken, the risk of postoperative bleeding is minimized. The reported preoperative characteristics and clinical outcomes of patients are shown per procedure [4, 6, 7, 11, 42–54] in Table 3. Indeed, the incidence of re-exploration for bleeding after remodeling in the high-volume institutions was only 2%, which was lower than that after reimplantation. Furthermore, it appears that the remodeling procedure, because it takes less time, prevents coagulopathy, especially in cases of acute aortic dissection or distal aortic involvement.

Long-term valve stability

Both procedures have undergone many technical modifications, and these have improved clinical outcomes. The long-term clinical outcomes of each procedure reported by high-volume centers are summarized in Table 3. Patients with certain pathological conditions [BAV, Marfan syndrome (MFS), or acute dissection, for example], pediatric patients, and patients with only one or two sinuses of Valsalva replaced were excluded from the analyses. Freedom from reoperation on the aortic valve is now around 90% or more at 5–15 years for both procedures. A majority of institutions specialize in one procedure or the other, and no randomized study has been carried out. Therefore, it is quite difficult to compare the two alternatives. David et al. performed both

Table 3 Characteristics and long-term outcomes of the aortic root remodeling procedure and the aortic valve reimplantation procedure

First author	Published year	Reference number	Number of cases	Severe AR	Bicuspid aortic valve	Marfan syndrome	Acute aortic dissection	Cusp repair	Early mortality [elective cases]	Re-exploration for bleeding	Freedom from reoperation	Freedom from AR II or more
Remodeling												
Yacoub	1998	4	158	28 (18%)	N.A.	68 (43%)	49 (31%)	13 (8%) ^a	14 (8.9%) [4.6%]	N.A.	85% @ 15 years	
Erasmí	2007	42	96	N.A.	13 (14%)	N.A.	21 (22%)	22 (23%)	4 (4.0%) [0%]	N.A.	89% @ 54.7 months	
Jeanmart	2007	11	48	9 (19%) (>IV)	11 (23%)	5 (10%)	0	23 (48%)	1 (2.1%) [2.1%]	7 (15%)	97% @ 5 years	97% @ 5 years
David	2010	43	61	11 (21%)	2 (3%)	26 (42%)	7 (12%)	32 (52%)	1 (1.6%)	N.A.	90.4% @ 12 years	82.6% @ 12 years ⁱ
Svensson	2011	44	72	7 (10%) (>IV)	17 (24%)	12 (17%)	19 (26%) ^b	N.A.	0	N.A.	85% @ 10 years	
Schäfers	2014	6	747	405 (54%)	290 (39%)	29 (4%)	59 (8%)	690 (92%)	15 (2.0%)	18 (2%)	91% @ 15 years	
Lansac	2017	7	177	32 (18%) (>IV)	59 (33%)	28 (16%)	2 (1%)	122 (69%)	5 (2.8%)	4 (2%)	89.5% @ 7 years	77.4% @ 7 years
Reimplantation												
Kallenbach	2005	45	284	18 (6%)	17 (6%)	54 (19%)	53 (19%)	18 (6%)	9 (3.2%) [1.3%]	12 (5%)	87.1 @ 10 years	
Svensson	2011	44	72	12 (18%) (>IV)	5 (7%)	23 (32%)	11 (15%) ^c	N.A.	0	N.A.	86% @ 10 years	
Leontyev	2012	46	179	2 (1%)	16 (9%)	31 (17%)	28 (16%)	32 (18%)	2 (1%)	16 (9%)	96% @ 5 years	94% @ 5 years ⁱ
Liebrich	2013	47	236	6 (3%)	35 (15%)	26 (11%)	14 (6%)	54 (23%) ^d	4 (1.7%) [1.3%]	6 (4%)	87 @ 10 years	
Kvitting	2013	48	233	28 (12%)	63 (27%)	102 (44%)	0	105 (45%)	2 (0.9%) [0.9%]	8 (3%)	92.2 @ 10 years	
Toeg	2014	49	68	26 (38%)	35 (52%)	4 (6%)	6 (9%)	61 (90%)	1 (1.5%)	N.A.	100% @ 3 years	
Coselli	2014	50	83	12 (14%)	6 (7%)	32 (39%)	3 (4%)	2 (2%)	1 (1%)	7 (8%)	87% @ 8 years	74% @ 8 years
Miyahara	2015	51	183	89 (49%)	37 (20%)	45 (25%)	21 (12%)	111 (61%)	3 (1.6%) [1.1%]	N.A.	92.2 @ 5 years	
Koolbergen	2015	52	97	10 (10%)	15 (16%)	54 (56%)	0	19 (20%) ^e	0	2 (2%)	94% @ 5 years	
De Paulis	2016	53	124	20 (16%) (>IV)	15 (12%)	21 (17%)	7 (6%)	8 (6%) ^f	2 (1.6%)	10 (8%)	90% @ 13 years	87% @ 13 years ⁱ
Esaki	2016	54	123	80 (65%) ^g	32 (26%)	8 (7%)	16 (13%)	N.A.	7 (5.7%)	9 (7%)	97% @ 7 years	
David	2017	55	333	66 (20%)	45 (14%)	128 (38%)	28 (8%)	213 (64%)	4 (1%) ^b	29 (9%)	97% @ 20 years	92% @ 20 years ⁱ

N.A. not applicable

^aCusp augmentation^bEmergent: 14 (21%)^cEmergent: 2 (3%)^dOnly central plication^eSubcommissural annuloplasty alone is not included^fOne cusp repair^g≥Moderate AR^hDeath within 90 daysⁱFreedom from moderate or severe AR

procedures in a relatively high number of patients: reimplantation in 296 patients and remodeling in 75 [15]. At up to 20 years after the procedure (mean 8.9 years), freedom from moderate or severe AR was similar between the two procedures ($p = .52$). Freedom from reoperation on the aortic valve was better after reimplantation than after remodeling, but the difference was not significant ($p = .07$). MFS was involved in up to 31% of patients who underwent remodeling without annuloplasty or with partial annuloplasty, but when these patients were excluded from the analysis, there was no reoperation nor recurrent AR after remodeling [15]. It appears that the two procedures provide similar long-term valve stability, and we expect even better outcomes with further advances in annuloplasty and grafts with sinuses. Indeed, a recent meta-analysis and a multi-institutional analysis confirmed that the two procedures yield comparable valve durability [55, 56].

Nonetheless, there are some subtle differences between two procedures in the following special settings.

BAV

There have been only a few reports on the long-term results of remodeling strictly for a BAV [6, 21, 57–62], and these reports are shown in Table 4. One report has been provided by the University of Saarland Medical Center, and this report covers the largest number and longest follow-up of patients treated by remodeling [6]. The 10-year freedom from reoperation rate (89%) after remodeling was comparable to that after reimplantation; however, the rate at 15 years (83%)

was inferior. The same group of authors later disclosed that the cumulative incidence of reoperation was 21.7% at 15 years [63]. However, their outcomes should be interpreted carefully. Patients with BAV tend to have a relatively large annulus, and this is a risk factor for recurrence of AR [18, 22]. Lack of annular support has also been identified as a risk factor for late failure [21, 64]. These authors' early patients were treated without annuloplasty, but in a more recent series, freedom from AR of grade 2 or more improved dramatically from 81 to 92% at 5 years with the addition of annuloplasty [6]. Another reason for the late disappointing results might be the aggressive approach taken by surgeons at Saarland. Cusp calcification and use of a pericardial patch were identified as risk factors for reoperation [63]. Triangular resection and a pericardial patch were applied, respectively, to 23 and 11% of the Saarland patients [64]. An expert has recommended, therefore, that remodeling should be the first choice for BAV patients unless heavy cusp calcification or relevant stenosis exists [14]. Long-term valve stability after remodeling for patients with BAV may become comparable to that after reimplantation by selecting appropriate candidates and adding annuloplasty.

MFS

According to a recent meta-analysis of 413 cases of MFS, the re-intervention rate was lower after reimplantation than after remodeling (0.7 vs. 2.4%/year, respectively) [65]. Only a few other reports comparing the late outcomes of the two valve-sparing root replacement surgeries for patients with

Table 4 Long-term outcomes of the aortic root remodeling procedure and the aortic valve reimplantation procedure in cases with the bicuspid aortic valve

First author	Published year	Reference number	Number of cases	Mean follow-up	Freedom from reoperation	Freedom from AR II or more
Remodeling						
Schäfers	2014	6	290	6.2 years (mixed)	89% @ 10 years, 83% @ 15 years	81% @ 5 years to 92% @ 5 years ^a
Reimplantation						
de Kerchove	2011	21	53 ^b	73 m	100% @ 6 years	100% @ 6 years
Forteza	2013	58	51	Median 36 months	100%	100%
Kari	2015	59	75	3 years	90% @ 2.8 years	100%
Richardt	2015	60	30	6.6 years		
Vallabhajosyula	2016	61	45 ^c	3.4 years	100% @ 5 years	96% @ 5 years
Miyahara	2016	62	41	39 months	89% @ 5 years	83% @ 5 years ^d
Fattouch	2017	63	65	68 months (mixed)	98% @ 5 years	98% @ 5 years

^aImproved with annuloplasty

^bAfter matching

^cType I alone

^dFreedom from more than mild AR

Table 5 Long-term outcomes of the aortic root remodeling procedure and the aortic valve reimplantation procedure in cases with Marfan syndrome

Authors	Year	Number of patients	Mean follow-up	Freedom from reoperation	Comments
Tanaka [66]	2011	7 53	Median 55 months	58% @ 10 years 58% @ 10 years	MFS included in 92% Remodeling: risk for reoperation (HR = 12.3, $P = .029$)
Kunihara [67]	2112	21 12	66 months	86% @ 7 years 92% @ 7 years	External suture annuloplasty in 7 patients, $P = .99$
Schmidtke [68]	2012	12 25	42 months	3 reoperation No reoperation	
Schoenhoff [69]	2015	5 24	6.5 years	40% @ 5 years 94% @ 5 years	$P < .0001$
David [70]	2015	25 121	Median 10 years	5% @ 15 years	Reimplantation: protective for reoperation (HR = 0.16, $P = .01$)
Price [71]	2016	29 69	Median 8.4 years	85% @ 10 years 97% @ 10 years	$P = .11$

The upper and lower column represents patients who underwent remodeling or reimplantation, respectively

MFS have been published (Table 5). In 4 of the 6 studies, remodeling was shown to be inferior to reimplantation in terms of late valve stability [66–71]. The patient groups were not large, however, and the follow-up periods varied. The data suggest that more secure annular stabilization is achieved for patients with MFS. Indeed, remodeling was performed in only one patient among 239 patients included in an international registry between 2005 and 2010 [72]. However, care must be taken in interpreting the results because annuloplasty had been combined with remodeling for only a small number ($n = 7$) of patients included in the studies listed in Table 5 [67]. We must await further clinical investigations to compare remodeling plus annuloplasty against reimplantation when a graft with sinuses, which is quite sophisticated, is used [73] to determine the best option for patients with MFS.

Acute aortic dissection

In the emergency acute aortic dissection setting, the question of which procedure to use to treat root disease remains unanswered. Most surgeons are reluctant to perform a time-consuming valve-sparing root replacement procedure because reducing myocardial ischemia time is crucial to saving these critically ill patients. Indeed, a recent meta-analysis of studies of aortic valve repair in the setting of acute aortic dissection revealed that aortic valve resuspension was performed in 95% of patients, with the remainder undergoing valve-sparing root replacement (reimplantation = 2.5% and remodeling = 2.5%) [74]. Otherwise, full root replacement with a composite graft and mechanical prosthesis is a widely accepted procedure in this situation,

although prosthesis-related complications remain a concern for relatively young patients [65].

There are several reports of valve-sparing root replacement performed for patients with acute aortic dissection [10, 75–83], and these are shown in Table 6. There are three reports from the Hannover group, each from a different time period. After the disappointing outcome of remodeling (freedom from reoperation = 38%) reported by Leyh, et al. [10], durability of the repair led most surgeons to favor reimplantation despite having to opt for a longer procedure time.

After a decade, Subramanian et al. and Urbanski et al. began replacing only one or two Valsalva sinuses by remodeling and reported a freedom from reoperation rate of 90–100% at 5 years [79, 80]. Patients with acute aortic dissection usually have relatively normal annulus and pliable cusps, so they should be optimal candidates for remodeling when root replacement is necessary. According to the author's experience in Homburg with 59 patients for whom remodeling was performed for acute aortic dissection involving the aortic root (annuloplasty performed in 6), freedom from proximal reoperation was 98% at 10 years, a rate that is comparable to that reported for reimplantation in similar patients [83].

With the technical considerations described above, the risk of postoperative bleeding might be reduced in this patient population. The incidence of re-exploration for bleeding after remodeling in the current era has been reported as 10.5% by Urbanski et al. [80] and 8% (since 2007) by the author's experience [83], which do not seem inferior to reimplantation (8–13% [77, 78]). Within the same institution performing both procedures, the incidence of re-exploration for bleeding after remodeling (28%)

Table 6 Long-term outcomes of the aortic root remodeling procedure and the aortic valve reimplantation procedure in cases with acute aortic dissection

Author	Year (studied period)	Number of patients	Early mortality	Re-exploration for bleeding	Mean follow-up	Freedom from AR > II	Freedom from reoperation
Graeter [75] (Homburg)	2000 (1995–1999)	17	11.8%			90.9% @ 2 years	100% @ 2 years
		5	0%			100% @ 2 years	100% @ 2 years
Leyh [10] (Hannover)	2002 (1995–2000)	8	17%		33 months		38 ± 23%
		22			22 months		95 ± 5%
Erasmí [76] (Luebeck)	2003 (1994–2001)	21	19%		30 months		76% @ 7.3 years
		15	20%		11 months		
Kallenbach [77] (Hannover)	2004 (1990–2003)	0	10.4%	8%	19 months		65 ± 27% @ 5 years
Farhat [78] (Bron)	2007 (02–12/2005)	0	6.7%	13%	11 months	100% @ 11 months	100% @ 11 months
Subramanian [79] (Leipzig)	2012 (1995–2010)	51 ^a	16%	28%	44 months		≅ 90% @ 5 years
		27	15%	33%	27 months		≅ 90% @ 5 years
Urbanski [80] (Bad Neustadt)	2016 (2002–2013)	54 ^a	1.9%	10.5%	5.2 years (6.1 years for survivors)	100% @ 48 months	100%
Leshnower [81] (Atlanta)	2015 (2005–2013)	0	4.7%		40 months	94% @ 40 months	100%
		43					
Beckmann [82] (Hannover)	2015 (2002–2011)	0	12.8%				95.2% @ 1 years
Kunihara [83] (Homburg)	2015 (1995–2013)	59	6.8%	17% (8% since 2007)	105 months	87 ± 6% @ 10 years	98 ± 2% @ 10 years
		0					

The upper and lower column represents patients who underwent remodeling or reimplantation, respectively

^aMost of cases (76%, 89%) underwent replacement of only 1 or 2 sinuses

was lower than that after reimplantation (33%) [79]. The shorter procedure time might be helpful in preventing coagulopathy in this critical setting.

Conclusion

With the technical advances and modifications described above, the differences between remodeling and reimplantation have narrowed, and both procedures yield excellent clinical results. However, some advantages of remodeling may be that less root dissection is necessary, the procedure time is shorter, and the hemodynamics is better. We suggest, then, that remodeling may be advantageous for high-risk patients, such as those with acute aortic dissection, those of advanced age, those with reduced ventricular function, those who require a concomitant operation, and those for whom prevention of a need for re-repair or replacement of the aortic valve will be challenging. Young athletes may also be candidates for remodeling

because of the physiological hemodynamics that can be expected with the procedure. It is important that we, as surgeons, understand the advantages and disadvantages of both remodeling and reimplantation and that we become skilled at both so that we can properly match patients to the appropriate treatment.

Compliance with ethical standards

Conflict of interest The author has declared no competing interest.

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