

## The Ross–Yacoub procedure for aneurysmal autograft roots: A strategy to preserve autologous pulmonary valves

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**Objectives:** Autograft dilatation is leading to an increase in root reoperations late after the Ross procedure. A 14-year clinical experience was reviewed to define the feasibility and outcome of the autograft valve–sparing root reoperation.

**Methods:** One hundred twenty-six patients surviving an average of  $7.4 \pm 9.9$  years after the Ross procedure underwent cross-sectional clinical and echocardiographic examination. Study end points were freedom from autograft dilatation (diameter  $>4$  cm or  $2.1$  cm/m<sup>2</sup>), root reoperation, root replacement, and functional outcome after the valve-sparing reoperation.

**Results:** Thirty-one (25%) patients had dilatation, with  $45\% \pm 9\%$  freedom at 14 years. In 14 (11%) patients an autograft aneurysm ( $>5.0$  cm) was found: 12 had reoperations at  $8.9 \pm 2.6$  years after the Ross procedure. Risk factors for root reoperation at multivariate analysis were root technique ( $P = .01$ ), root dilatation ( $P = .001$ ), and follow-up duration ( $P = .06$ ). Two patients had root replacement, and 10 (83%) had remodeling with valve preservation (8 Yacoub procedures and 2 sinotubular junction/ascending aorta procedures); all survived reoperation. Absence of severe autograft insufficiency ( $P = .04$ ) and convergent-type aneurysm ( $P = .05$ ) were associated with successful valve preservation. Fourteen-year freedom from root reoperation was  $80\% \pm 7\%$ , and freedom from full root replacement was  $97\% \pm 4\%$ . At  $3.2 \pm 1.5$  years (range, 0.2–4.8 years) after root reoperation, all patients are in New York Heart Association class I and are medication free: 9 of 10 patients have mild autograft valve insufficiency or less, and 1 required valve replacement 51 months after remodeling. One patient carried out 2 uncomplicated pregnancies 3 and 4 years after the Ross–Yacoub procedure.

**Conclusions:** Root reoperation with pulmonary valve preservation is feasible in the majority of patients with autograft aneurysms, allowing for maintenance of normal quality of life. Referral of patients with a dilated root before the appearance of severe valve insufficiency increases the likelihood of pulmonary valve sparing. Functional behavior of remodeled autograft roots is rewarding; however, continued observation is warranted. (J Thorac Cardiovasc Surg 2010;139:536–42)

Forty years after introduction into clinical practice, the Ross procedure is experiencing declining fortune.<sup>1</sup> Although incremental morbidity caused by allograft repair of the right side of the heart was partly expected,<sup>2</sup> late complications related to emerging autograft root and valve pathology were mostly unforeseen.<sup>3–5</sup> In fact, root dilatation with or without valve dysfunction has clearly turned into the Achilles' heel of the Ross procedure, exceeding by far the prevalence and severity of right-sided valve dysfunction.<sup>1,4,5</sup>

Several strategies have been proposed to deal with autograft root dilatation after the Ross procedure, including

avoidance<sup>3,6</sup> or support of the root technique,<sup>7</sup>  $\beta$ -blocker therapy, and, when required, elective root replacement<sup>4,8</sup> or remodeling with pulmonary valve preservation.<sup>8–13</sup> Because only the latter option has the potential to respect the “Ross paradigm” (ie, to guarantee a living, autologous valve allowing normal quality of life), a systematic approach was prospectively adopted at our institution that entails elective root remodeling (the Ross–Yacoub procedure) according to criteria proposed for native aortic aneurysms in patients with a bicuspid aortic valve.<sup>14</sup> The results with such a strategy are reported.

### MATERIALS AND METHODS

Institutional review board approval was obtained for the conduct of this study, and the board waived the need for patient consent.

### Patients

Between May 1994 and November 2008, 129 consecutive patients (108 male and 21 female patients aged  $22.3 \pm 17.3$  years [range, 0.08–49 years]) underwent the Ross procedure at our institution. Indication for surgical intervention was valve insufficiency in 80 (62%) patients, stenosis in 18 (14%) patients, or mixed lesion in 31 (24%) patients; 90 (70%) patients had a bicuspid valve, and 24 (19%) patients had an aneurysmal (diameter

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Disclosures: None.

Read at the 2008 American Heart Association Meeting, New Orleans, La, November 9–12, 2008.

Received for publication Feb 7, 2009; revisions received June 18, 2009; accepted for publication Aug 10, 2009; available ahead of print Oct 21, 2009.

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0022-5223/\$36.00

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doi:10.1016/j.jtcvs.2009.08.019

>5 cm) ascending aorta or aortic root. Twenty (16%) patients had undergone 1 or more prior operative cardiac procedures (aortic valvotomy, n = 10; balloon valvuloplasty, n = 5; coarctation repair, n = 6; subaortic obstruction relief, n = 3; and ventricular septal defect repair, n = 2).

### Ross Procedure Technique

Three operative techniques were used to implant the autologous pulmonary valve in the aortic position: subcoronary grafting (26 patients), inclusion cylinder (43 patients), and free-standing root replacement (60 patients), according to techniques described elsewhere.<sup>5</sup> Freestanding root replacement was the technique of choice in children (<18 years), whereas inclusion cylinder and subcoronary grafting were preferred in adults. The latter 2 were applied nonrandomly, with variable frequency over time: subcoronary grafting was historically the first technique used and has returned to be the preferred one nowadays. Routine buttressing of inflow (annular) and outflow (ascending aortic) suture lines with strips of glutaraldehyde-fixed autologous pericardium was abandoned after 1998. Associated procedures were performed in 24 patients, including reductive tailoring aortoplasty in 19 patients and ascending aortic replacement in 2 patients, all with aortic aneurysms, and repair of membranous ventricular septal aneurysm, repair of atrial septal defect, and coronary artery bypass grafting, each in 1 patient, respectively.

### Clinical Follow-up

In the present cross-sectional follow-up study (median, 6.7 years; range, 0.5–14.6 years), all 126 late survivors (100%) were assessed by means of direct physical examination at our clinic (n = 98) in conjunction with echocardiographic evaluation or by means of telephone interview (n = 28). Patients who were suspected to have aneurysmal dilatation of the aorta (diameter >5 cm) at echocardiographic examination underwent concomitant magnetic resonance imaging of the chest and yearly imaging thereafter.

### Echocardiographic Data and Measurements

All patients underwent transthoracic echocardiographic examinations at discharge and were scheduled for repeat examinations on a yearly basis thereafter. The same experienced sonographer at our institution undertook cross-sectional follow-up echocardiographic investigation or reviewed examinations performed elsewhere to eliminate interobserver variability. Autograft dimensions were measured as previously described<sup>5</sup> at 4 different levels: (1) aortoventricular junction (aortic annulus), (2) sinus of Valsalva, (3) sinotubular junction, and (4) proximal ascending aorta. Aortic insufficiency was graded with the use of standard criteria.<sup>5</sup>

### Technique of Reoperation

During the early stage of the experience, indication for reoperation on the aortic root was deferred until the aorta exceeded 5.0 to 5.5 cm and the autograft valve showed at least moderate regurgitation. Subsequently, the criterion proposed for elective aortic root operations in patients with Marfan syndrome or bicuspid aortic valve disease<sup>14</sup> was prospectively adopted. This criterion recommends elective aneurysmal resection when the aortic cross-sectional area ( $r^2\pi$ ) indexed to body height exceeds 10.<sup>14</sup> Preventive dissection of femoral vessels for peripheral cardiopulmonary bypass was performed in all patients before repeat sternotomy. Autograft valve sparing, either by means of remodeling of the sinotubular junction (ascending aortic aneurysm) or aortic root remodeling (aortic root aneurysm) with a modified Yacoub procedure, was the intended treatment in all patients. Competence of the autograft valve at the end of aneurysm repair was tested by using intraoperative transesophageal echocardiographic analysis. Conversion to valve replacement during a second period of cardiopulmonary bypass and cardiac arrest was performed when residual autograft valve insufficiency was graded as moderate or greater. As a reference during the same time interval (1994–2008), 158 native aortic valve-sparing procedures (138 Yacoub remodeling and 20 David I reimplantation procedures) were performed at our institution.

### Statistical Analysis

Categorical variables are reported as absolute numbers and percentages. Continuous variables are expressed as means  $\pm$  standard deviations. Time-related events were described by using the Kaplan–Meier estimate and compared with the log-rank test. Primary end points of the study were as follows: freedom from autograft dilatation (root diameter >4 cm or 0.21 cm/m<sup>2</sup> at any of the 4 levels examined), freedom from any reoperation on the autograft, freedom from reoperation on the autograft root, and freedom from replacement of the autograft root. Secondary end points were the clinical and functional status of patients after root remodeling. Univariate analysis was performed to identify factors predictive of a need for root reoperation and of the success of root remodeling with valve preservation. Multivariate analysis was performed by using a multiple logistic regression method to identify risk factors for time-related occurrence of autograft dilatation and root reoperation. Variables entered in the analysis included age at the time of the Ross procedure, sex, body surface area, diagnosis (regurgitation, stenosis, and mixed), bicuspid aortic valve, prior aortic procedure, operative technique (subcoronary, cylinder inclusion, and root replacement), use of pericardial strips, associated procedure, length of follow-up, aneurysm (diameter >5 cm or 2.6 cm/m<sup>2</sup>) of the sinus of Valsalva, sinotubular junction or ascending aorta before and after the Ross procedure, grade of autograft valve regurgitation, and morphology of the aortic aneurysm before reintervention (classified as tubular, convergent, or divergent). The SAS software (release 9.1; SAS Institute, Inc, Cary, NC) was used for statistical analysis. A comprehensive review of all reported cases of autograft root remodeling with valve preservation and of root replacement<sup>4,8-12,15-23</sup> was also undertaken.

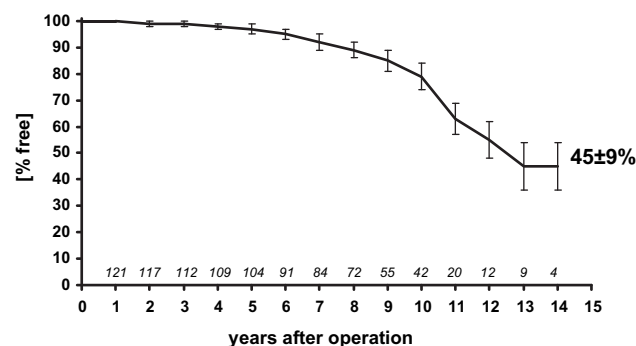
## RESULTS

### Survival

Hospital mortality for the entire clinical series was 1.5%: both patients died of a cardiac cause. Patients were followed for an average of  $7.4 \pm 9.9$  years (range, 0.5–14.6 years). One late sudden death was recorded 1 year after surgical intervention, resulting in an overall survival of  $98\% \pm 1\%$  at 14 years. The 126 long-term survivors constitute the focus of the present study.

### Autograft Dilatation

Dilatation at 1 or more of the autograft levels was encountered in 31 (25%) patients: freedom from dilatation was  $45\% \pm 9\%$  at 14 years (Figure 1). The prevalence of autograft dilatation was higher among patients undergoing the



**FIGURE 1.** Actuarial freedom from root dilatation in 126 long-term survivors after the Ross procedure. Error bars represent  $\pm$  standard deviations. Patients at risk are reported over the x-axis.

**TABLE 1. Variables associated with aortic root dilatation**

	Odds ratio	95% CI	P value
Root technique	2.75	0.77–9.86	.001
Follow-up after the Ross operation	1.28	0.30–5.44	.002

CI, Confidence interval.

root replacement technique: 24 (41%) of 58 as opposed 6 (14%) of 43 having inclusion cylinders and 1 (4%) of 25 having subcoronary implants (root vs inclusion or subcoronary,  $P = .004$ ). Multivariate analysis showed use of a root replacement technique ( $P = .001$ ) and length of follow-up ( $P = .002$ ) as risk factors for dilatation (Table 1). Among patients with dilatation, aneurysmal diameter was identified in 14 (11%; 12 male and 2 female patients) at a mean time of  $7.7 \pm 2.8$  years (range, 4.3–13.6 years) after the Ross procedure: 12 had root reoperation, as described below, and 2 are awaiting elective operations.

### Autograft Root Reoperation

During the study period, 18 patients underwent a total of 22 cardiac procedures, with no hospital mortality: freedom from any cardiac reoperation was  $77\% \pm 5\%$  at 14 years for the entire Ross series. Among these, 12 (67%) patients required an autograft root reoperation at an average of  $8.9 \pm 2.6$  years (range, 6.1–14.3 years) after the original operation. All but 1 (cylinder inclusion) had undergone autograft root replacement. Univariate analysis identified younger age at the time of the Ross procedure ( $P = .01$ ), a history of prior cardiac surgery ( $P = .02$ ), use of a root replacement technique ( $P = .01$ ), autograft dilatation ( $P = .001$ ), and length of follow-up ( $P = .002$ ) as risk factors for root reoperation. The latter 3 risk factors proved significant also at multivariate analysis (Table 2). Root reoperation was planned electively in 11 patients and on an emergency basis in 1 patient who experienced acute autograft root dissection.<sup>13</sup> At the time of the operation, severe pathology of the sinus and sinotubular and ascending aortic segments with normal-appearing pulmonary valve leaflets, as represented in Figure 2, was a rather constant finding. Root remodeling with valve preservation by using the Yacoub technique in 10 patients and sinotubular junction remodeling with ascending aortic replacement in 2 patients proved successful in 10 (83%) root reoperations. In the first 2 patients of the series, both with severe autograft regurgitation, satisfactory competence of the valve could not be obtained after Yacoub remodeling, leading to full root replacement. There was no hospital mortality after root reoperation. Histologic findings of the excised pulmonary autograft roots showed moderate-to-severe elastic fiber fragmentation in all, mild cystic medial necrosis in 5 patients, severe cystic medial necrosis in 1 patient with dissection, fibrosis of media and adventitia in 7 patients, and increased intimal thickness in 8

**TABLE 2. Variables associated with aortic root reoperation**

	Odds ratio	95% CI	P value
Root dilatation	7.49	0.99–22.55	.001
Root technique	2.54	1.40–9.72	.01
Follow-up after the Ross operation	1.27	0.91–1.59	.06

CI, Confidence interval.

patients. Fourteen-year freedom from any root reoperation was  $80\% \pm 7\%$ , whereas freedom from full root replacement was  $97\% \pm 4\%$  ( $P = .01$ , Figure 3). Among the 10 patients having successful valve preservation, 1 eventually required valve replacement, as reported below. Univariate analysis showed larger root diameters ( $P = .05$ ), absence of severe autograft valve insufficiency ( $P = .04$ ), and convergent-type aneurysms ( $P = .05$ ) to be more common among patients having successful valve-sparing root reoperations (Table 3).

### Functional Outcome After Valve-Sparing Reoperation

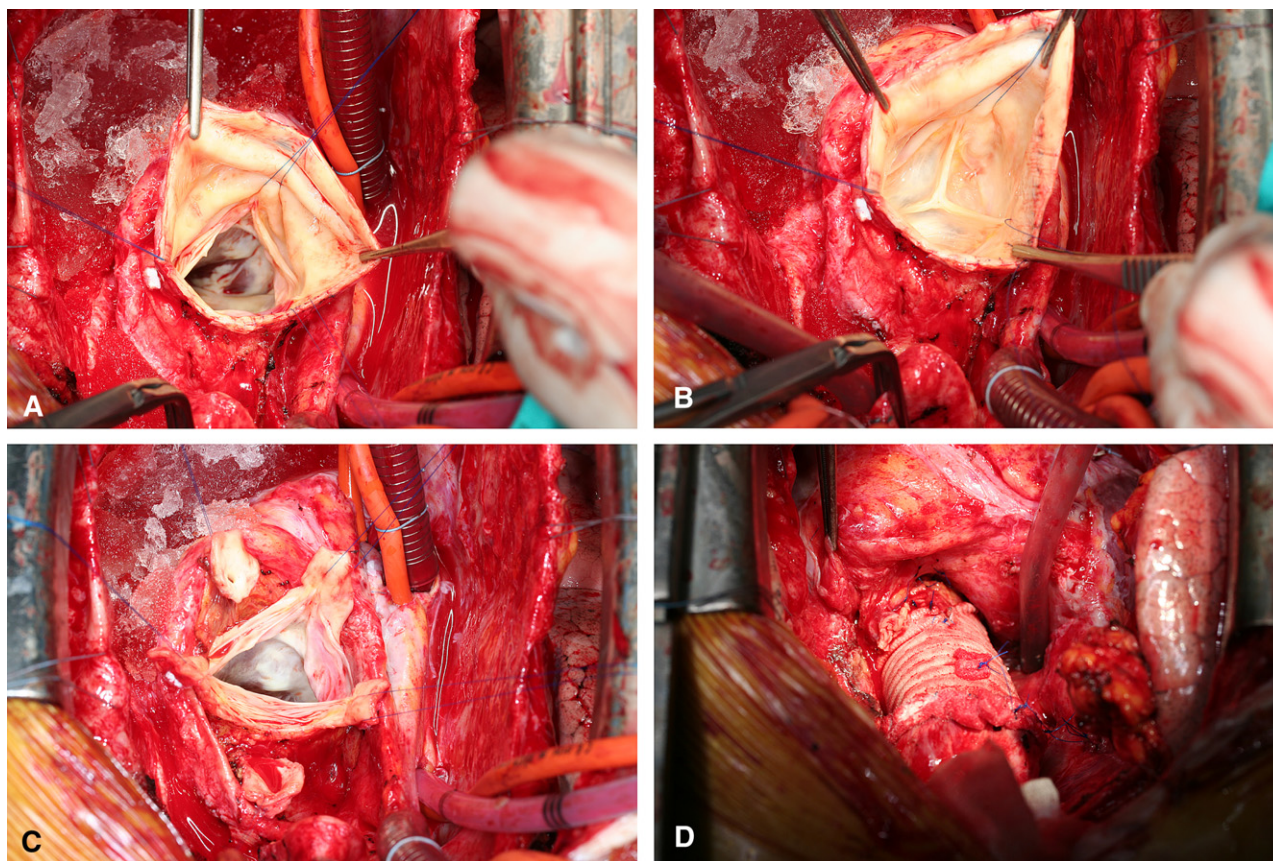
Patients were followed for an average of  $3.2 \pm 1.5$  years (range, 0.2–4.8 years), and only 1 patient, who required reoperation, experienced adverse cardiovascular events. Age at follow-up was  $33.0 \pm 10.7$  years, ranging from 21.5 to 55.5 years; all patients were in New York Heart Association class I and free of cardiac medications, including warfarin. Eight patients were employed full-time, and 2 were completing university education. All performed regular exercise, and 3 engaged in strenuous sports. One woman, who was 28 years old at the time of the redo operation, carried out 2 successful pregnancies with cesarean section delivery 3 and 4 years after the Yacoub procedure, respectively. Follow-up echocardiographic assessment, which was available in all patients, showed trivial residual valve regurgitation in 7 patients, mild residual valve regurgitation in 2 patients, and severe residual valve regurgitation in the 1 patient who had presented with dissection and required aortic valve replacement 4.3 years after the Yacoub procedure.

### DISCUSSION

This study adds further evidence to numerous other observations showing that autograft root dilatation with or without valve dysfunction is the most taxing adverse event late after the Ross procedure.<sup>1,3-5,17,20-24</sup> This is particularly true when the operation is performed as a root replacement technique. Ironically, the very same modification to the original Ross procedure that made it readily reproducible and thus highly popular in the 1990s has nowadays turned into the reason for the vanishing enthusiasm for this elegant procedure.<sup>1</sup>

In addition, the current study suggests that a policy of resection of autograft root aneurysms based on standardized criteria can be associated with a high rate of pulmonary valve





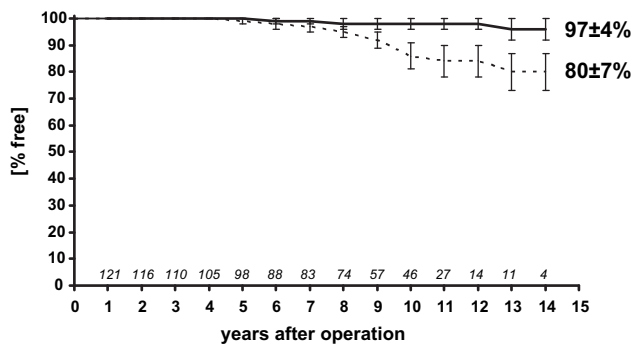
**FIGURE 2.** Intraoperative view of the autograft root in a patient undergoing root remodeling with valve preservation (Ross–Yacoub procedure). A, The ascending aorta has been transected at the level of the original autograft–aorta anastomosis. Three stay sutures have been placed at the valve commissures, and the leaflets were retracted to expose the left ventricular outflow tract. Marked dilatation of the sinus of Valsalva segment is apparent. B, Same view as A, only with the autograft valve in the closed position. The leaflets are normal looking, and coaptation is preserved. C, The autograft root has been entirely excised, except for a thin rim of tissue at the left ventricular–autograft junction (annulus). The harvested coronary buttons are also visible. D, Completed repair after Dacron vascular graft implantation.

salvage in institutions with experience in valve-sparing root surgery. This strategy, herein arbitrarily named the Ross–Yacoub procedure, allows the Ross paradigm, with its attendant excellent quality of life, to live on.

#### Autograft Dilatation

The prevalence of dilatation in the present analysis was somewhat lower than previously reported by our group (25% vs 34%); however, the proportion of patients having root aneurysms caused by progression increased 3-fold (11% vs 4%).<sup>3</sup> Explanations might include a shift from root replacement to the subcoronary grafting technique in the last 6 years of practice, application of strict criteria for patient selection (conversion to alternative prosthetic devices in case of even slight geometric mismatch of aortic–pulmonary roots), and growing satisfaction with native aortic valve repair, with root remodeling when required, in young patients with regurgitant bicuspid valves. The latter has become the treatment of choice for these patients, who constitute the largest group in the present and other Ross

series yet also those at greater risk for late failure.<sup>1,3,4,20,22,23</sup> Practically, this has resulted in a 3-fold decrease in the number of Ross procedures performed yearly at our center (from an average of 15 to 5). The present study confirms prior work by Sievers and associates<sup>6</sup> showing that dilatation is rare in patients undergoing subcoronary implantation. Furthermore, it shows that dilatation is uncommon (14%) and generally stable in patients undergoing cylinder inclusion yet highly prevalent and often progressive in those undergoing autograft root replacement. Indeed, the latter variable, as well as length of follow-up, continues to prove to be associated with dilatation at multivariate analysis, as previously observed.<sup>5,23,24</sup> Comparison with prior studies is hampered by the paucity of series comparing the 3 operative techniques.<sup>3,7,16,23</sup> Nonetheless, the observation that both the prevalence of root dilatation and freedom from root dilatation in Ross series exclusively using the root technique are strikingly similar to the results herein corroborates the effect of the operative technique.<sup>1,3,4,20-24</sup> On the contrary, the previously reported protective effect conferred by pericardial



**FIGURE 3.** Actuarial freedom from root reoperation (*dashed line*) and from full root replacement (*solid line*) in 126 long-term survivors after the Ross procedure. *Error bars* represent  $\pm$  standard deviations. Patients at risk are reported over the *x-axis*.

buttressing of proximal and distal autograft anastomoses<sup>5</sup> did not emerge at extended follow-up. This might reflect the inability of annular and sinotubular junction support to prevent sinus of Valsalva dilatation (convergent aneurysm), as reported by Kouchoukos and colleagues,<sup>4</sup> which represents the typical pattern of pathologic remodeling of free-standing autograft roots.<sup>4,5</sup>

**Autograft Root Reoperation**

Overall freedom from any cardiac reoperation in the current series was comparable with that seen in most other long-term (>10 years) follow-up series, including 69% at 13 years reported by Klieverik and coworkers,<sup>1</sup> 75% at 10 years reported by Kouchoukos and colleagues,<sup>4</sup> 74% at 16 years reported by Elkins and associates,<sup>22</sup> and 81% reported at 12 years by de Kerchove and coworkers.<sup>23</sup> Early reoperations, which can occur with any surgical technique, generally reflect institutional learning curves (technical error), whereas late reoperations highlight limitations inherent with initially successful procedures. It is noteworthy that most (12/18 in the present study), if not all, of the late reinterventions were required for autograft root pathology.<sup>1,3,4,20-23</sup> This resulted in disappointing freedom from root reoperation that was not dissimilar from that seen in other reports.<sup>1,4,22,23</sup> Quite expectedly, the negative influence of root dilatation, root technique, and duration of follow-up proved significant at multivariate analysis (Table 2), which is in agreement with prior work from our group,<sup>5</sup> as well as most other groups.<sup>1,3,4,20,21,23</sup>

**Ross–Yacoub Procedure**

The rationale for the Ross–Yacoub procedure lies in clinical and basic research evidence. The strategy of repairing dysfunctional autografts was inspired by the work of Elkins and associates,<sup>22</sup> who have since shown successful salvage of autologous pulmonary valves in one fourth of Ross reoperations. Leading the concept further, several authors

**TABLE 3.** Variables associated with successful valve preservation

	Valve preservation (n = 10)	Valve replacement (n = 2)	P value
Root diameter before root redo (mm)	56 $\pm$ 4	52	.05
Severe AI before root redo	1	2	.04
Convergent-type aneurysm before root redo	7	0	.05

AI, Autograft valve insufficiency.

reported anecdotal experience with remodeling of the autograft root with valve preservation in the past 7 years,<sup>8-13</sup> with the expectation of results similar to those reported for native aortic aneurysms. Experience from Sievers and associates<sup>6</sup> showing that subcoronary implants are immune from dilatation at midterm follow-up lends theoretic support to valve-sparing autograft remodeling because this can be viewed as a late conversion to a “modified” subcoronary Ross procedure. More importantly, basic research evidence derived from studies on congenital heart disease, in which the native pulmonary root works in the systemic circulation since infancy, suggests that pulmonary vascular tissue never truly remodels to resemble normal aortic vascular tissue.<sup>25</sup> This casts serious doubts on the possibility that pulmonary autograft roots, although viable, might ever function as normal aortic roots, even when the Ross procedure is performed in young infants. Clinical observations on neo-aortic root dilatation being out of proportion with somatic growth in infants and children support this hypothesis.<sup>24</sup> On the contrary, evidence is now available showing that the pulmonary valve transplanted in the systemic circulation can remodel to resemble the structure of a normal aortic valve.<sup>26</sup> One study on explanted aneurysmal autografts, however, suggests that this process might not always be able to preserve normal mechanical properties.<sup>17</sup> In summary, the autograft valve leaflets might remodel toward an aortic phenotype, but the autograft root will likely never do so.

The indication for autograft root reoperation is controversial, particularly when valve dysfunction is absent or mild. Conservative management of autograft root pathology, until recently conceivable,<sup>5</sup> appears narrow sighted in light of available evidence on the progression of valve regurgitation and, most importantly, on abrupt complications, such as dissection, which is reported in 5% of aneurysmal autografts (Table 4).<sup>8-13,15-19,22,23</sup> Based on these considerations, we prospectively applied surgical indications, adopting the criterion proposed by Svensson and colleagues<sup>14</sup> for native root pathology in patients with Marfan syndrome and a bicuspid aortic valve. The choice was based on 2 considerations. First, similar to Marfan syndrome and bicuspid aortic valve roots, autografts dilate and might dissect. Second, histologic changes in aneurysmal autografts are similar to those seen in bicuspid aortic walls, as observed herein and by others.<sup>17</sup>

TABLE 4. Overall experience with valve-sparing aortic root replacement after the Ross procedure

Reference	No. of patients	Age (y)	Sex	Years s/p Ross	Ross technique	Autograft dissection	Technique	Outcome (survived)	Histology	FU (y)
Sundt and coworkers, 2001 <sup>8</sup>	1	19	Male	7	Root	–	Yacoub	1	EF, CMN	–
Ley and coworkers, 2002 <sup>9</sup>	1	39	Male	2.3	Root	–	David I	1	–	1.1
Schmidtke and coworkers, 2002 <sup>10</sup>	1	42	Male	10	Root	–	Yacoub	1	–	0.4
Ishizaka and coworkers, 2003 <sup>11</sup>	4	16.5 ± 7.9	Male	4.0 ± 2.9	Root	–	Yacoub + anuloplasty	4	EF, MPS	0.5 ± 0.3
Masetti and coworkers, 2003 <sup>12</sup>	1	46	Male	12	Root	–	Yacoub	1	–	0.5
Nemoto and coworkers, 2004 <sup>15</sup>	1	2.5	Male	2	Ross/Konno	–	Repair + anuloplasty	1	–	0.5
Kincaid and coworkers, 2004 <sup>16</sup>	1	39	Male	6	Root	1	AAR + RC sinus	1	CMN	0.33
Schoof and coworkers, 2006 <sup>17</sup>	2	30.6 ± 10.5	Male	6.1	Root	–	NS	1	EF, SMC, F	–
Watanabe and coworkers, 2006 <sup>18</sup>	1	38	Male	6	Root	–	David I	1	EF, CMN	–
De Kerchove and coworkers, 2009 <sup>23</sup>	7	–	–	8.7	Root	–	David I	7	–	1.7 ± 1.8
Luciani and coworkers, present report	8	29.8 ± 10.5	6 Male/2 female	9.2 ± 2.7	Root 7, inclusion 1	1/8	Yacoub 8	8	EF, SMC, CMN	3.2 ± 1.5
Overall valve-sparing procedures	28	28.0 ± 10.1	19 Male/2 female	7.4 ± 2.5	27 Root, 1 inclusion	2/28	15 Yacoub 9 David 4 other	28/28	17/18 EF	1.9 ± 1.3

FU, Follow-up; EF, elastin fragmentation/loss; CMN, cystic medial necrosis; MPS, mucopolysaccharide deposition; AAR, ascending aortic replacement; NS, not specified; RC, right coronary; SMC, smooth muscle cell hypertrophy; F, fibrosis; NC, noncoronary sinus.

Analysis of worldwide clinical experience shows that of 103 reoperative procedures on the autograft root reported during the last 12 years,<sup>4,8-12,15-23</sup> 28 (26%) resulted in preservation of the autologous pulmonary valve (Table 4). Reports of valve-sparing operations were mostly anecdotal, except for this study and 3 other series comprising 2 to 8 patients,<sup>11,20,23</sup> with clinical and echocardiographic follow-up exceeding 1 year in only this study and 2 other reports (overall average, 1.8 ± 1.3 years; median, 0.5 years; range, 0.3–4.6 years).<sup>9,23</sup>

Several techniques have been applied to autograft root remodeling, although the Yacoub procedure was the most common (15 [54%] of 28 patients) and the one used in the present series. Advantages of the Ross–Yacoub procedure include avoidance of left and right ventricular outflow tract adhesions, which can be tenacious; greater adaptability to individual sinus anatomy, as suggested by Ishizaka and coworkers<sup>11</sup>; and avoidance of Dacron prosthesis-to-autograft leaflet contact by means of recreation of sinus of Valsalva anatomy, which might cause abrasion of the thin pulmonary valve leaflets. The same reasons are the ones, we believe, that make adoption of the reimplantation technique (David I procedure) less desirable in this clinical setting, although very recent reports have shown initial success with the latter as well.<sup>9,18,23</sup> One potential disad-

vantage of the Yacoub technique is the inability to stabilize the annulus. However, prior evidence from our institution has shown the latter to be less exposed to significant dilation over time than the sinus portion,<sup>5</sup> which is specifically addressed by Yacoub-type remodeling. The present report shows that systematic application of the Ross–Yacoub procedure can result in higher and satisfactory freedom from prosthetic autograft valve replacement (97% vs 80% freedom from root reoperation), which is similar to what shown with autograft valve repair by Brown and colleagues,<sup>20</sup> Elkins and associates,<sup>22</sup> and de Kerchove and coworkers.<sup>23</sup> Variables associated with success of the Ross–Yacoub procedure, albeit marked by weak statistical power, recommend surgical intervention in patients with convergent aneurysm morphology and before the onset of relevant valve insufficiency. Functional outcome and quality of life after the Ross–Yacoub procedure are truly rewarding and identical to those after the Ross procedure. This is perhaps the most compelling argument in favor of a more complex repair, which theoretically exposes patients to the risk of future reoperation to a greater extent than composite aortic root replacement. Indeed, analysis of worldwide experience confirms that the majority (74%) of autograft root aneurysms have been dealt with by complete root replacement, which represents a solid treatment modality.



Nonetheless, one must be cognizant that patients undergoing the Ross procedure are those who have already traded the risk of reintervention for superior quality of life (eg, sports and pregnancy), and in our experience most of them continue to do so, even when choosing options for reoperation on the autograft root. In addition, experience is now growing with percutaneous replacement of dysfunctional homografts in patients undergoing the Ross procedure: in the foreseeable future, transcatheter aortic valve therapy, be it percutaneous or transapical,<sup>27</sup> will also be available for patients undergoing Ross and Ross–Yacoub procedures with failing autografts. Although midterm valve function was rewarding in the current study, one case of late deterioration in the patient who had presented with acute autograft dissection<sup>13</sup> recommends caution in adopting the Ross–Yacoub procedure in this setting. In addition, even if the present is the largest clinical experience with this strategy, it is also the one with the longest available follow-up (Table 4). It is fair to state that root-remodeling operations are complex, particularly in patients undergoing the Ross procedure, and should be performed in centers with vast experience. Elsewhere, composite autograft root replacement represents the safest option.

### Limitations of the Study

The present work shares the limitations inherent with any retrospective nonrandomized study. In addition, the independent effect of root and sinotubular junction remodeling and the effect of earlier time of the Ross procedure were not directly assessed. Furthermore, the number of autograft root-remodeling operations performed to date, both at our institution and worldwide, remains too small and follow-up remains too short to define superiority over standard root replacement.

In conclusion, extended follow-up after the Ross procedure continues to show autograft root pathology as the most common late complication. Strict patient selection and avoidance of the root technique might reduce the prevalence of late dilatation. Elective pulmonary valve-sparing root reoperation before significant valve regurgitation is associated with satisfactory midterm outcomes and quality of life, allowing the Ross paradigm to live on.

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