

Ross Operation in the Adult: Long-Term Outcomes After Root Replacement and Inclusion Techniques

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Background. Dilatation of the pulmonary autograft is a major concern after root replacement for the Ross operation. The inclusion technique would avoid this drawback, but few data are available on the long-term results of this technique. We retrospectively analyze long-term results of both techniques.

Methods. Of 218 patients undergoing the Ross operation between 1991 and 2006, 148 (68%) had root replacement and 70 (32%) underwent the inclusion technique. The mean age of the patients was 40 ± 10 years (range, 16 to 64). Mean follow-up was 94 ± 44 months (range, 13 to 196). Echocardiographic controls were available in 197 patients. Proximal aorta dilatation was defined as diameter > 40 mm.

Results. In the root and inclusion groups, 10-year overall survival was $94\% \pm 4\%$ and $97\% \pm 4\%$, respectively. Freedom from autograft reoperation was $81\% \pm 10\%$ and $84\% \pm 13\%$, respectively. Main cause of reoperation was autograft dilatation in the root group (13 of 16) and valve prolapse in the inclusion group (5 of 6).

Freedom from proximal aorta dilatation was $57\% \pm 12\%$ and $80\% \pm 15\%$, respectively. In the root group, dilatations ($n = 48$) affected systematically the autograft sinuses or sinotubular junction, whereas in the inclusion group, dilatations ($n = 10$) affected principally the ascending aorta (8 of 10). Freedom from severe autograft regurgitation was $86\% \pm 9\%$ and $83\% \pm 13\%$, respectively. Root technique, follow-up length, and preoperative aortic valve regurgitation were predictors of proximal aorta dilatation.

Conclusions. In the long term, both techniques showed excellent survival and similar rates of autograft failure. For root replacement, autograft dilatation was the main cause of failure. For the inclusion technique, the autograft, but not the ascending aorta, was protected against dilatation and autograft valve prolapse was the main cause of failure.

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The Ross operation, first described in 1967 by Donald Ross [1], is considered the treatment of choice for aortic valve disease in children and represents an interesting alternative in selected young adults [2–4]. Since the late 1980s, the Ross operation has been widely performed, with three different main pulmonary autograft implantation techniques described: the original subcoronary implantation; the root replacement; and the inclusion (or cylinder) technique [1, 3, 5]. Of these, the root replacement technique has received the greatest acceptance because of its easier implantation technique, a wider indication field (pediatric population and root aneurysms), and better early and midterm results [5–7]. However, with longer follow-up, a progressive dilatation of the pulmonary autograft was demonstrated after the root replacement technique [8–11], and the aneurysmal evolution of the autograft has been shown to be a

worrisome complication leading to an increased rate of reoperation [12–14].

To prevent this late drawback, different techniques of autograft reinforcement have been proposed [5, 6, 15, 16]. One of these is the inclusion technique, in which the full autograft root is included as a cylinder inside the native aortic root. This technique seems efficient in preventing autograft dilatation, but limited data are available regarding the long-term results [10, 11]. The purpose of this study was to assess the long-term incidence of autograft dilatation, regurgitation, and reoperation in a large cohort of adult patients who underwent Ross operation with root replacement (root group) or the inclusion technique (inclusion group). We analyze the results of those two techniques and identify predictors of autograft dilatation and regurgitation.

Patients and Methods

From June 1991 to October 2006, 218 adult patients underwent Ross operation using the root replacement technique ($n = 148$; 68%) or the inclusion technique ($n = 70$; 32%). Operations were carried out at the Cliniques

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Table 1. Patient Demographics and Preoperative Characteristics

	All Patients (n = 218)	Root Technique (n = 148, 68%)	Inclusion Technique (n = 70, 32%)
Mean age (years, [range])	40 ± 10 [16–64]	39 ± 11 [16–64]	42 ± 10 [12–60]
Male	166 (76)	114 (77)	52 (74.3)
Complex cardiac malformation	5 (2.3)	3 (2)	2 (3)
Previous aortic valve procedure (no. of patients)	42 (19)	39 (26.4)	3 (4)
Replacement ^a	24 (11)	23 (15.5)	1 (1.4)
Balloon valvotomy	3 (1.4)	3 (2)	0
Surgical valvotomy/plasty or subaortic stenosis resection	21 (9.6)	18 (12)	3 (4)
Previous sternotomy	40 (18)	37 (25)	3 (4)
Aortic valve hemodynamic lesions			
Aortic stenosis	73 (34)	44 (30)	29 (41)
Aortic regurgitation	67 (31)	45 (30)	22 (32)
Aortic stenosis plus aortic regurgitation	78 (36)	59 (40)	19 (27)
Native aortic valve morphology			
Tricuspid	68 (31)	47 (32)	21 (30)
Bicuspid	134 (62)	88 (60)	46 (66)
Other (dyplasic, monocusp)	14 (6)	11 (7)	3 (4)
Unknown	2 (1)	2 (1)	0
Etiology of present pathology			
Congenital	132 (60.5)	84 (57)	48 (69)
Degenerative ^b	41 (19)	30 (20)	11 (16)
Endocarditis	19 (9)	13 (9)	6 (8)
Rheumatic	16 (7)	11 (7)	5 (7)
Prosthesis mismatch	9 (4)	9 (6)	0
Prosthesis thrombosis	1 (0.5)	1 (1)	0
Preoperative aorta enlargement ^c	56 (26)	39 (26)	17 (24)
Root enlargement	19 (9)	15 (10)	4 (6)
Ascending aorta enlargement	43 (20)	29 (20)	14 (20)
Impaired LVEF <50%	14 (6)	11 (7)	3 (4)

Values in parentheses are percentages. ^a Mechanical valve (n = 13), allograft (n = 9), xenograft (n = 2). ^b Patients with degenerative disease of native aortic valve (n = 30) or structural degeneration of biological valve (n = 11). ^c Patients reported with supranormal proximal aorta dimensions.

LVEF = left ventricular ejection fraction.

Universitaires Saint-Luc (n = 186; 85%) or at the Cliniques Universitaires Mont-Godinne (n = 32; 15%) by one of two senior surgeons (J.R. [51%, root, n = 69; inclusion, n = 43] or G.E.K. [49%, root, n = 79; inclusion, n = 27]). All patients had preoperative transthoracic echocardiography (TTE), completed by transesophageal echocardiography, if necessary. Perioperative data were collected from medical records and surgeons' operative reports (Table 1). The Institutional Review Board of the clinics approved the study.

Operative Procedure

During the study period, both surgeons had a similar surgical approach. The root technique, applicable in all circumstances, was the routine procedure; the inclusion technique, less frequently used, was avoided in case of native root aneurysm. Root technique was also favored in patients having previous aortic valve procedures and when associated procedures were necessary (Tables 1 and 2).

The autograft was implanted orthotopically inside the aortic annulus with interrupted or continuous sutures. Proximal suture line buttressing was performed in 60 pa-

tients (27.5%) with a Teflon (Impra Inc, subsidiary of L.R. Bard, Tempe, AZ) felt or a pericardial strip. The distal suture line was performed at the level of the sinotubular junction, or higher in some patients having the root technique. Ascending aorta procedures are described in Table 2. The right ventricular outflow tract (RVOT) was reconstructed with a cryopreserved pulmonary homograft in 206 patients (94.5%). When homograft was not available, a stentless xenograft (n = 12; 5.5%) was used.

Clinical and Echocardiographic Follow-Up

Clinical follow-up data were collected by a questionnaire sent to all patients. When a questionnaire was not returned or was incomplete, phone contact was made with the patient or with a relative or physician. Subsequent hospitalization and routine visit data were collected from hospital records and cardiologists' reports.

New TTE controls were requested for all patients having had no examination within the past 12 months. The TTE controls were preferably performed in the surgical centers. For patients preferring to undergo TTE controls by their referent cardiologists, standard TTE

Table 2. Intraoperative and Postoperative Data

Variable	All Patients (n = 218)	Root Technique (n = 148, 68%)	Inclusion Technique (n = 70, 32%)
Proximal suture line buttressing	60 (27.5)	47 (32)	13 (19)
Ascending aorta procedures	42 (19)	32 (22)	10 (14)
Replacement with Dacron graft	29 (13)	19 ^b (13)	10 (14)
Longitudinal plication	9 (4)	9 (6)	0
Replacement with long autograft	4 (2)	4 (3)	0
Associated procedures (no. of patients)	36 (16.5)	30 (20)	6 (9)
Mitral valve repair	19 (9)	16 (11)	3 (4)
Preoperatively planned CABG	6 (3)	5 (3)	1 (1.5)
CABG for ischemia after Ross procedure	4 (2)	4 (3)	0
Ventricular septal defect repair	2 (1)	1 (0.5)	1 (1.5)
Aortic arch replacement/repair	1 (0.5)	1 (0.5)	0
Myomectomy/subaortic valve resection	7 (3.5)	7 (5)	0
Repeat CPB for residual insufficiency	4 (2)	4 (3)	0
Cardiopulmonary bypass time (min)	157 ± 30	159 ± 33	152 ± 23
Cross-clamp time (min)	129 ± 22	130 ± 24	127 ± 18
Postoperative morbidity (no. of patients)	38 (17)	29 (20)	9 (13)
Bleeding/tamponade	16 (7)	13 (9)	3 (4)
Perioperative myocardial infarction ^a	5 (2.3)	3 (2)	2 (3)
Pacemaker	1 (0.5)	1 (0.7)	0
Transient ischemic attack/stroke	3 (1.5)	2 (1.5)	1 (1.5)
Pneumopathy/sepsis	14 (6)	9 (6)	5 (7)
Transient renal insufficiency	6 (3)	5 (3.4)	1 (1.5)
Grade 2+ autograft regurgitation at discharge	13 (6)	7 (5)	6 (9)
Early mortality	3 (1.5)	3 (2)	0
Late mortality	5 (2.3)	4 (2.7)	1 (1.5)

^a Myocardial infarction was as new Q-wave on discharge electrocardiography.

^b In 3 patients, ascending aorta was replaced for calcification or intraoperative lesion.

CABG = coronary artery bypass graft surgery; CPB = cardiopulmonary bypass.

protocols, joined to the clinical questionnaire, were provided for the echocardiographers, who had to fill out the forms and send them back to the researchers. Encoded echocardiographic data were issued from the most recent TTEs and from the last ones before redo surgery in patients needing autograft reoperation. Autograft valve function was analyzed by measuring the severity of regurgitation, which was graded semiquantitatively as none, mild, moderate, or severe, and by measuring the transvalvular peak and mean gradients. The proximal aorta dimension was evaluated by measuring its transversal diameter at the level of the sinuses of Valsalva, sinotubular junction, and proximal ascending aorta. At any level, a diameter greater than 40 mm was considered as dilatation and 50 mm or greater as an aneurysm. Autograft dilatation was defined as dilatation at the level of the sinuses of Valsalva or the sinotubular junction, or both. One hundred and nine patients (55%) had TTE controls performed at one of the two surgical centers, and 88 (45%) had TTE controls performed at referent centers.

Follow-up completeness was 97%. Mean follow-up was 94 ± 44 months (median, 93; range, 13 to 196), giving a total of 1,601 patient-years. Follow-up was slightly shorter in the inclusion group (91 ± 47 months) than in the root group (95 ± 42 months). The TTE controls were

obtained in 197 patients (90%); 134 of them had a root replacement, and 63 had an inclusion. The mean echocardiographic follow-up was 87 ± 43 months (median, 84; range, 6 to 196).

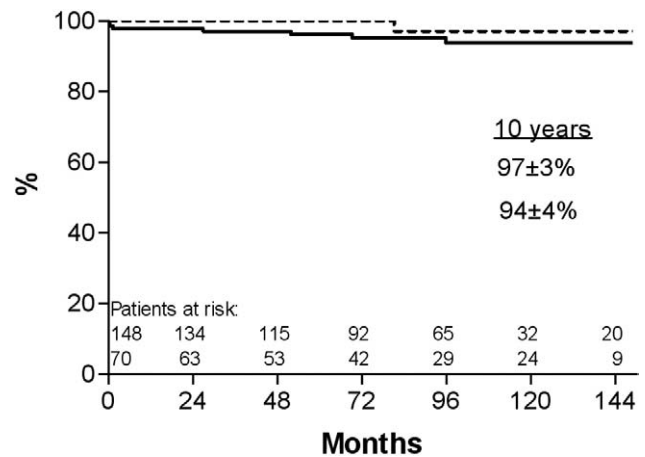
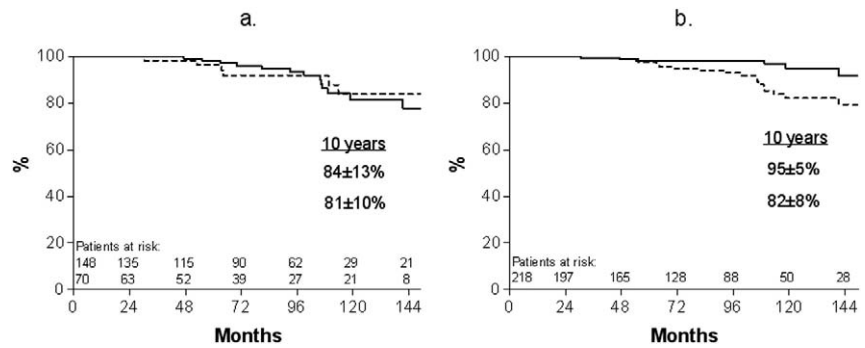


Fig 1. Actuarial overall survival in the root group (solid line) and inclusion group (dashed line).

Fig 2. (a) Actuarial freedom from autograft reoperation in the root group (solid line) and inclusion group (dashed line). (b) Actuarial freedom from autograft reoperation (dashed line) and autograft replacement (solid line) in the all cohort.



Statistical Analysis

Continuous variables were reported as the mean \pm SD and categorical variables as proportions. The χ^2 test was used where appropriate to compare variables. Survival curves were computed with the Kaplan-Meier method (Prism 2.0; GraphPad Software, La Jolla, CA). The variables age, sex, native valve morphology, presence and type of previous aortic valve procedure, previous sternotomy, hemodynamic lesion type, history of hypertension, autograft implantation technique, ascending aorta replacement with Dacron (Gelweave, Vascutek Ltd, a Terumo Company, Renfrewshire, Scotland) graft, proximal suture line buttressing, associated procedure, cardiac arrest time, follow-up length, and proximal aorta dilatation 45 mm or more were tested in univariate and multivariate analyses for the endpoints autograft dilatation and moderate or greater autograft regurgitation. In multivariate analysis, multiple logistic regression modeling was performed. Variables significant at the p less than 0.1 level in univariate analysis and clinically meaningful variables were entered in the model. Results were considered statistically significant at the p 0.05 or greater level. The SAS software (release 9.1) was used in the statistical analysis (SAS Institute, Cary, NC).

Results

Mortality

Three patients (1.4%) died during the early postoperative period (less than 30 days), 1 from massive cerebral bleeding, 1 from sudden death, and 1 from acute pulmonary edema. During the follow-up period, 5 patients died (2 to 7 years after surgery); of them, only 2 died of cardiac

causes (arrhythmia, sudden death; Table 2). Ten-year overall survival was 94% \pm 4% in the root group and 97% \pm 3% in the inclusion group (Fig 1).

Morbidity

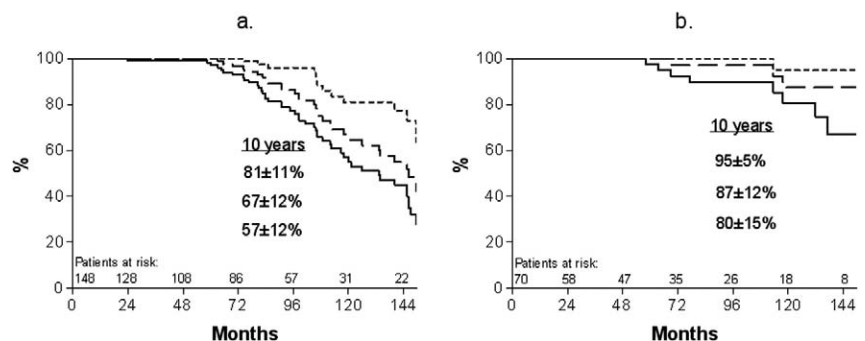
Relevant early postoperative complications are listed in Table 2. During follow-up, thromboembolic and bleeding events occurred in 3 patients (transient ischemic attack, $n = 1$; stroke, $n = 1$; cerebral bleeding, $n = 1$). Both patients having embolic events suffered from atrial fibrillation, and the patient having a bleeding event had no anticoagulation nor antiaggregation therapies while bleeding occurred. The linearized rate of a thromboembolic or bleeding event was 0.2% per patient-year. One autograft endocarditis episode occurred in a patient from the root group, who required reoperation for this reason.

Reoperations

Autograft reoperation was required in 22 patients. In 2 of them, combined autograft and RVOT reoperation was necessary. These 2 patients had replacement of pulmonary homograft after 12 years because of stenosis, and no other RVOT reintervention occurred during the follow-up period. Ten-year freedom from autograft reoperation was 81% \pm 10% in the root group and 84% \pm 13% in the inclusion group (Fig 2a). Ten-year freedom from RVOT reintervention was 100% in both groups.

Mean delay to autograft reoperation (range, 2.5 to 14.8 years) was 8.7 \pm 3 years in the root group and 6 \pm 2 years in the inclusion group. In the root group, indications for reoperation were autograft aneurysm with mild ($n = 2$), moderate ($n = 2$), or severe ($n = 9$) regurgitation and severe regurgitation without dilatation ($n = 3$). In the inclusion group, indica-

Fig 3. (a) Actuarial freedom from proximal aorta diameter greater than 40 mm (solid line), 45 mm or greater (broken line), and 50 mm or greater (dashed line) in the root group. (b) Actuarial freedom from proximal aorta diameter greater than 40 mm (solid line), 45 mm or greater (broken line), and 50 mm or greater (dashed line) in the inclusion group.



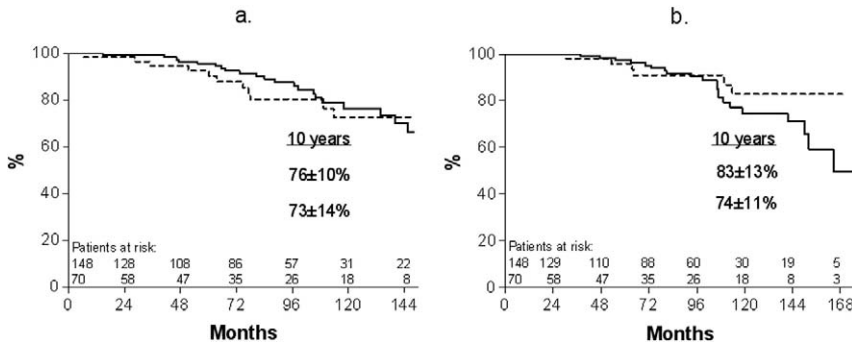


Fig 4. (a) Actuarial freedom from moderate or greater autograft regurgitation in the root group (solid line) and inclusion group (dashed line). (b) Actuarial freedom from autograft failure (defined as autograft reoperation or aneurysm or severe regurgitation) in the root group (solid line) and inclusion group (dashed line).

tions were severe regurgitation (n = 5) and ascending aorta aneurysm with severe regurgitation (n = 1). Identified mechanisms of regurgitation were proximal aorta dilatation (root, n = 11; inclusion, n = 1), proximal aorta dilatation and leaflet prolapse (root, n = 1), leaflet prolapse (root, n = 1; inclusion, n = 5), false aneurysm of the proximal suture line (root, n = 1), and endocarditis (root, n = 1). The mean proximal aorta diameter in case of reoperation for dilatation was 53 ± 4 mm (range, 45 to 60 mm).

In 6 patients, a failed autograft was replaced with a composite graft (n = 3), an aortic homograft (n = 2), or a stentless valve (n = 1). In the remaining 16 patients (root, n = 12; inclusion, n = 4), the autograft valve could be preserved using a sparing procedure (reimplantation technique, n = 7), autograft valve repair (n = 4), or supracoronary aortic replacement (n = 5). Ten-year freedom from autograft valve replacement was 95% ± 5% (Fig 2b). After a mean of 20 ± 22 months (range, 1 to 64), TTE controls in patients having autograft valve preservation showed no to mild regurgitation in 13 and moderate regurgitation in 3 of the patients having isolated valve repair.

Echocardiographic Data

In the following analysis, echocardiographic data before redo were considered for patients having autograft reoperation.

AUTOGRAFT DILATATION. Of 197 patients with TTE controls, proximal aorta dilatation was observed in 58 patients (29%; root, n = 48; inclusion, n = 10); of them, 36 (18%; root, n = 32; inclusion, n = 4) had 45 mm or greater dilatation, and 16 (8%; root, n = 15, inclusion, n = 1) had aneurysm. Ten-year freedoms from proximal aorta dilatation greater than 40 mm, 45 mm or greater, and 50 mm or greater were, respectively, 57% ± 12%, 67% ± 12%, and 81% ± 11% in the root group and 80% ± 15%, 87% ± 12%, and 95% ± 5% in the inclusion group (Fig 3a and b).

In the root group, among the patients showing dilatation, 22 (55%) had the larger diameter measured at the level of the sinotubular junction, 19 (40%) had the larger diameter measured at the level of the sinuses, and 7 (15%) had sinuses and sinotubular junctions of similar dimensions. In the inclusion group, among the patients showing dilatation, 2 presented sinuses dilatation (41 and 42 mm) with normal sinotubular junction; both had an autograft inclusion inside an already enlarged native

sinuses (40 and 45 mm, respectively) on preoperative echocardiography. Three patients with normal sinuses had a dilated sinotubular junction with a maximal diameter measured at the level of the ascending aorta (one aneurysm), and the last 5 patients had dilatation strictly localized on the ascending aorta. Of the 8 patients with ascending aorta dilatation, 4 had preoperative enlargement, for which nothing was done during Ross operation (Tables 1 and 2).

In the subgroup of patients having ascending replacement with a Dacron graft at the time of Ross (n = 29, Table 2), 1 patient had a root aneurysm and 5 had a dilatation (range, 42 to 44 mm); all 6 were in the root

Table 3. Univariate and Multivariate Analyses

Variable	Odds Ratio	95% CI	p Value
Predictors of proximal aorta dilatation (≥45 mm)			
Univariate			
Male sex	2.9	1–8.7	0.04
Preoperative AV regurgitation	2.9	1.4–6.2	0.003
Preoperative AV disease	0.4	0.2–1	0.04
Root technique	4.7	1.6–14	0.003
Follow-up length (month) ^a	—	—	0.001
Multivariate			
Preoperative AV regurgitation	3.8	1.9–7.9	0.004
Root technique	7	2.7–18.3	0.003
Follow-up length (month) ^a	1.02	1.01–1.03	0.003
Predictors of moderate or greater autograft regurgitation			
Univariate			
Male sex	3.6	1.2–10.7	0.01
Preoperative AV regurgitation	2.1	1–4.3	0.04
Proximal aorta dilatation (≥45 mm) at follow-up	4.2	1.9–9.1	0.0002
Multivariate			
Male sex	3.1	1.0–9.3	0.045
Proximal aorta dilatation (≥45 mm) at follow-up	3.7	1.7–8.3	0.0007

^a Continuous variable at the difference of the unmarked categorical variables.

AV = aortic valve; CI = confidence interval.

group. In the subgroup of patients with ascending aorta plication ($n = 9$), 2 had dilatation of the sinotubular junction (45 and 52 mm). And in the subgroup receiving long autograft ($n = 4$), all had autograft dilatation or aneurysm (range, 45 to 59 mm).

AUTOGRAFT FUNCTION. Of 197 patients with TTE controls, autograft regurgitation was absent in 54 (28%), mild in 101 (51%), moderate in 22 (11%), and severe in 20 (10%) patients. Ten-year freedom from moderate or greater regurgitation was $73\% \pm 14\%$ in the root group and $76\% \pm 10\%$ in the inclusion group (Fig 4a). Moderate or greater regurgitation was significantly more frequent among patients with autograft dilatation (≥ 45 mm, 44% versus < 45 mm, 16%; $p = 0.003$), and its incidence increased in patients with aneurysm (62%).

Considering autograft failure as the need for reoperation or the presence of aneurysm or severe regurgitation at follow-up, 10-year freedom from autograft failure was $75\% \pm 11\%$ in the root group and $83\% \pm 13\%$ in the inclusion group (Fig 4b). Autograft valve peaks (range, 2 to 23 mm Hg) and mean gradients (range, 1 to 10 mm Hg) were similar in the root group (7 ± 4 mm Hg and 4 ± 2 mm Hg) and inclusion group (7.2 ± 3 mm Hg and 4 ± 1.4 mm Hg).

Univariate and Multivariate Analyses

Results of univariate and multivariate analyses for predictors of autograft dilatation and moderate or greater regurgitation are detailed in Table 3. In multivariate analysis, root technique, preoperative aortic regurgitation, and follow-up length were independent predictors for autograft dilatation. Autograft dilatation and male sex were predictors of autograft regurgitation.

Comment

In this study, we confirm the excellent long-term survival after Ross operation in the adult population. The pulmonary autografts show stable and physiologic behavior regarding transvalvular gradients and thromboembolic or infectious events [3, 4]. However, we showed also an 18% rate of autograft reoperation at 10 years, mainly due to autograft dilatation or regurgitation. Equivalent or slightly higher reoperation rates have already been reported by several other authors using the root and inclusion techniques [12–14]. In this study, the outcomes analysis after root or inclusion techniques showed a similar rate of autograft failure, but the main mechanisms leading to failure seemed different in the two techniques.

Pulmonary Autograft Dilatation

In recent studies describing autograft dilatation, the root technique is unanimously incriminated as a predictor for dilatation [10, 11, 13, 17, 18]. The rate of autograft dilatation, calculated on serial echocardiographic assessments, was reported by Takkenberg and coworkers [11] at 0.5 mm/year in an adult population and by Pasquali and associates [17] at 2 mm/year in a mixed pediatric and young adult population. In this study, 10-year freedom from autograft dilata-

tion was 81% considering autograft aneurysms, 67% considering autograft diameters 45 mm or greater, and 57% considering diameters 40 mm or greater. Similar rates were reported by several other authors [13, 17, 18].

In multivariate analysis, next to the root technique and the follow-up length, the presence of preoperative aortic regurgitation was also an independent predictor of autograft dilatation. One explanation may be that the patients with aortic regurgitation usually have larger non-calcified annulus in comparison to patients with aortic stenosis. This relative suppleness of the very proximal support of the autograft may predispose to dilatation of the proximal part of the autograft but is unlikely related to dilatation of the distal part of the autograft. In statistical analysis, medical history of hypertension was not found predictor of dilatation probably because many of these patients have a good medical control of hypertension. A more realistic evaluation of hypertension would have needed multiple controls in prospective way. Nevertheless, we believe that systemic hypertension play a significant role in the development of autograft dilatation and that an optimal control of hypertension is crucial after root replacement since the immediate postoperative period.

Regarding the role of autograft length in the root technique, we showed systematic dilatation in patients with long autograft and a maximal diameter more frequently observed at the level of the sinotubular junction. On the basis of these results, supracommissural segment of the autograft seems more prone to dilatation, and for this reason the use of long autografts should be avoided contrarily to what was advised in earlier reports in case of ascending aorta dilatation [19]. In the root technique, autograft is better when it is as short as possible, with the distal suture line reinforced with a Teflon strip or extended with a Dacron graft. If those reinforcement techniques do not fully protect against autograft root dilatation, some data suggest a benefit from such support of the sinotubular junction [13].

Several authors have shown the efficacy of the inclusion technique in avoiding autograft dilatation after mid-term follow-up [10, 11, 13]. In this study, we confirm those results after a long-term follow-up. Indeed, although some dilatations were observed in the inclusion group at follow-up, they were much less frequent and severe than in the root group. Moreover, in the rare cases of sinotubular junction dilatation, an ascending aorta dilatation present at the time of Ross or evolving during follow-up seemed to be the cause of subsequent dilatation. Once again, these findings support the potential benefice to reinforce the sinotubular junction.

Pulmonary Autograft Regurgitation

Autograft dilatation and autograft valve prolapse were the main mechanisms of regurgitation observed in our study. As described in the native aortic valve, dilatation of the aortoventricular junction or sinotubular junction may induce regurgitation, despite normally appearing leaflets, by outward displacement of the commissures [10–13]. Because the dilatation process is progressive and occurs relatively

slowly over time [11, 17], this type of valve dysfunction appears relatively late during the follow-up (mean reoperation delay, 9 ± 3 years; range, 5.3 to 15).

In patients having autograft reoperation, valve prolapse was confirmed intraoperatively in 6 patients who did not present with concomitant autograft dilatation; of those, 5 had an inclusion technique. Looking at earlier TTE controls in these patients, we observed that an eccentric regurgitation jet was already described on discharge TTE in 3 of these patients, and that severe eccentric regurgitation developed within the first 4 postoperative years in all of them. These findings suggest the evolutive potential of an eccentric jet that corresponds to leaflet prolapse. They explain also the relative earlier reoperation delay found in the inclusion group and the “early” superiority of the root replacement reported by short- to midterm studies [6–8]. Some authors have affirmed that the early superiority of root replacement was related to a better respect of the root and leaflet geometry with this technique, rather than with the intra-aortic techniques (subcoronary and inclusion) [4]. On the other hand, Sievers and associates [20] reported recently very good long-term results with the subcoronary technique in a large cohort of patients.

Like other surgeons have done before in selected patients with autograft failure [5, 13], we have preserved the autograft valve by using sparing and repair techniques developed for aortic valve pathologies [21]. Naturally, this approach has raised some concerns about the durability of the repair. If macroscopically, the autograft valves appear, in the majority of cases, of good quality and free from calcification, microscopically, some authors have reported structural alteration of the leaflet, consisting essentially of fibrous thickening [22, 23]. Conversely, other authors have demonstrated an adaptive remodeling of the autograft valve structure toward that of the native aortic valve [24]. Actually, using an autograft preservation approach, we could preserve the valve in 74% of the reoperations, and after almost 2 years of follow-up, those patients showed an acceptable valve function.

Study Limitations

One limitation of this study is the origin diversity of the echocardiographic data with the variability that it induces in the measures. However, inclusion of TTE data from referent centers allowed us to avoid selection bias induced by the tendency to refer patients with autograft failure back to the original surgical center. Effectively, the incidence of autograft dilatation and severity of regurgitation were higher in TTEs issued from investigational centers versus referent centers (21% versus 15% and 14% versus 6%, respectively). Another limitation is the missing data on annulus dimension, which play a potential role in the development of autograft dilatation and regurgitation. Finally, the absence of randomization between both techniques precluded statistical comparison and limits the interpretation of the results. Further studies are necessary to precise risk factors of dilatation in the

root technique and to determine best indications for each technique.

Conclusion

In conclusion, this long-term follow-up study shows an excellent survival after Ross operation in the adult population; however, the autografts carry a significant risk of failure, principally due to dilatation and valve prolapse. Autograft dilatation is the main cause of failure in patients having root replacement, and the presence of preoperative aortic regurgitation seems to favor dilatation. The inclusion technique protects the autograft, but not the ascending aorta, against dilatation; however, this advantage is counterbalanced by failures due to autograft valve regurgitation on valve prolapse.

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INVITED COMMENTARY

Progressive accumulation of knowledge is best facilitated by sound data, robust analysis, and responsible conclusions. In the past, surgical developments were often based on the pioneering of committed individuals; nowadays, additional new steps are frequently based on practical logics. Often, developments are supported by authority rather than by evidence-based methodology.

The original introduction of the Ross procedure was clearly an example of successful pioneering. Later on, progressive dilatation of the autograft in an important number of patients was observed at long-term follow-up. In this regard, surgeons and centers suggested supportive surgical techniques to continue to benefit from the advantages of the autograft while reducing the negative effects of progressive dilatation.

De Kerchove and coworkers [1] add another step in this sequence. Their contribution confirms the findings of progressive dilatation in the unsupported autograft and claims that the inclusion technique results in less dilatation. Reoperations occurred in both groups at a comparable rate, however, because after inclusion-autograft procedures, more aortic regurgitation, due to prolapse, was observed and necessitated reoperation. In addition, de Kerchove and associates were successful in repairing the regurgitant autograft valves in an important number of patients.

Although these findings are certainly important and confirm the feasibility of these surgical approaches, it should be clear that the series of inclusion, as a means of preventing a complication of the autograft procedure, was selected at the surgeon's discretion and was guided by a size match of the aorta and the autograft. The presented data are not the result of a randomized or systematic study, and comparisons can therefore not be made. In addition, it cannot be ruled out that the mismatched autografts have an intrinsic risk of progressive dilatation, influencing the relative frequency of this observation in the supported autografts.

It is also important to realize that microscopic studies of explanted autograft tissue show degeneration of the autograft wall as well as of the valvular tissue. Repairing these valves, and thereby additionally treating a complication of the autograft procedure, apparently works for the presented duration of observation, but careful follow-up is of eminent importance because these valves are definitely at risk for further deterioration. Thus, it is crucial that standardized echocardiographic follow-up is organized and conducted by the surgical center itself, because this will provide the most responsible conclusions.

The evolution towards restricting the autograft procedure to the pediatric age group raises another concern, because in this age group, inclusion techniques can rarely be applied.

De Kerchove and associates are to be congratulated with their results, but in considering whether to follow their steps, it is important to carefully assess at what stage the level of evidence regarding the autograft procedure and consequent repairs is, on the road from an authority-based approach to an evidence-based strategy.

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