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Autograft Reinforcement to Preserve Autograft Function after the Ross Procedure

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List of abbreviations

AR	aortic regurgitation
CABG	coronary artery bypass graft
CI	confidence interval
LV	left ventricle
n.s.	non-significant
R	reinforcement
+R	with reinforcement
-R	without reinforcement
Root	root replacement
SC	subcoronary
SD	standard deviation
SE	standard error
STJ	sinotubular junction

1. Introduction

1.1 The problem of heart valve replacement

Operations on heart valves are the second most frequent cardiac surgical interventions. During the year 2007 more than 21.000 isolated heart valve operations were performed in Germany with a tendency to increase with time [1]. The vast majority of these operations involve the aortic valve (68% of all isolated heart valve procedures). The pathophysiology of aortic valve disease is well studied, and if left untreated it results in a lethal outcome. Despite an increasing interest in reconstructive surgery of the aortic valve in the latest years, the majority of aortic valve procedures replace the patient's diseased aortic valve, with a biological or mechanical prosthesis which bears significant disadvantages in comparison to the native human aortic valve.

1.2 The quest for the ideal heart valve replacement

The initial enthusiasm after the first implantation of mechanical valves [2] soon weaned off due to thromboembolic complications. Thereafter, various designs were implemented to reduce their thrombogenic potential. Bench engineering, investigations in animals, and clinical studies emphasized the importance of hemodynamics in valve design. Design criteria have been formulated. The materials have to be chemically inert, compatible with human tissue, atraumatic to blood, and nonthrombogenic. They also have to retain their structural properties over many years. Moreover it has to be technically feasible to implant the prosthesis securely in an appropriate physiologic position. Despite improved hemodynamics and the application of thromboresistant alloys and advanced ceramics, the goal of substituting the use of antiplatelet agents for lifelong anticoagulant therapy remains until now elusive.

Dr. Alain Carpentier, in the late 1960s, paved the way for the development of the "biological" valve prosthesis. Carpentier referred to this stent-mounted tissue valve as a "*bioprosthesis*" [3], a hybrid of biologic and mechanical structures. Clinical investigations of these valves confirmed that there was a low thromboembolic risk, which eliminated the need for anticoagulation. The current consensus on the choice of prosthetic valves recommends the use of biological prosthesis on patients older than 60-65 years old, in which it is largely expected that the biological prosthesis will most probably outlive the patient's life expectance. In young patients the long term performance and durability of biological valves remains disappointing due to the very high prevalence of mid and late term structural valve deterioration, eventually mandating a valve re-replacement after the second decade [4] [5].

1.3 An alternative approach for the treatment of aortic valve disease: The Ross procedure

The pulmonary autograft procedure for the treatment of aortic valve disease, first performed by Donald Ross in 1967 [6], may be the only aortic valve replacement technique that theoretically at least, provides all advantages of a viable, autologous, tissue valve replacement warranting physiologic aortic valve hemodynamics and motion, as well as an unrestricted "cross talk to surrounding structures" [7] including the aortic root, the left ventricle and ascending aorta [8, 9]. During the Ross procedure, the patient's native pulmonary valve is harvested and implanted in the aortic position, while a pulmonary homograft is implanted in the pulmonary position. The Ross procedure is being performed in experienced centers with low operative mortality and is associated with lower incidence of macro- and microembolism that any other mechanical or biological replacement [6, 8, 10, 11, 12] without the need for lifetime anticoagulation therapy. This makes the Ross procedure especially appealing to young patients, whose quality of life may be affected by alternative valve substitutes, mainly due to the lifelong anticoagulation, necessary with mechanical prostheses and the limited durability of biological valves in young patients [4, 5].

Although initially performed as a subcoronary transplant [13], the technical complexity of the operation made the reproduction of Ross's initial [13] and late results [6] with the subcoronary technique difficult [14]. This lead to the development of the total root replacement technique [15, 16], in which the complete aortic root is entirely replaced by the pulmonary root (**Figure 1, page 7**). This technique has received broad acceptance with 81% of patients of the International Ross Registry [17].

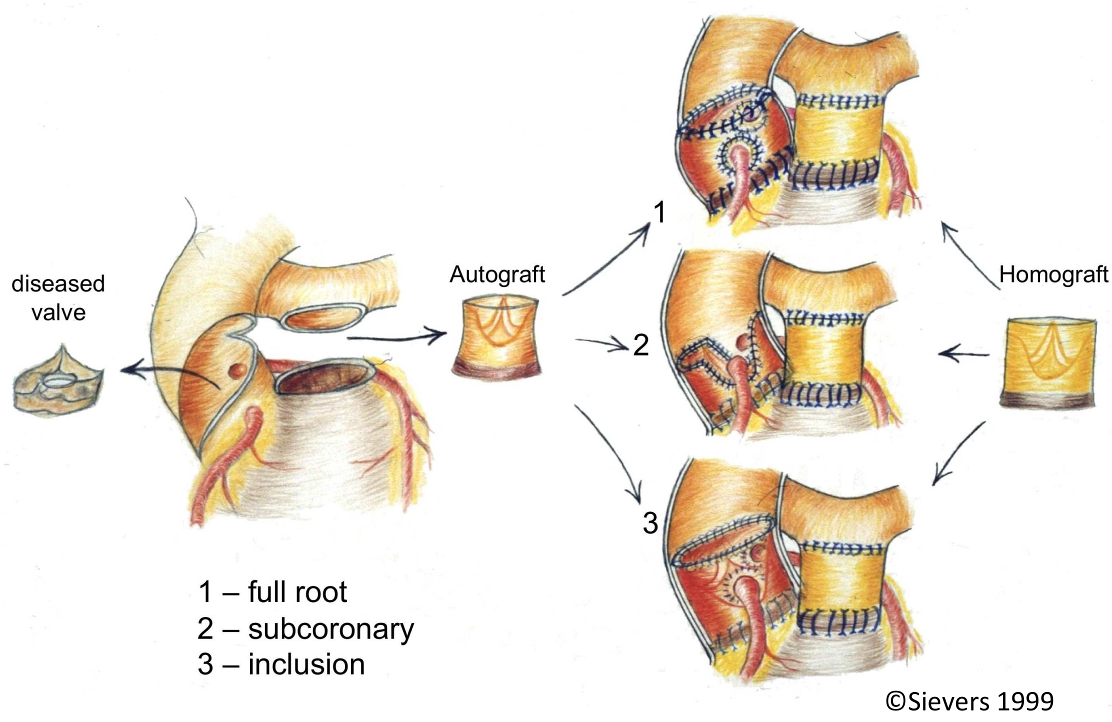

Figure 1. The 3 main techniques utilized in the Ross procedure: (1) root replacement, (2) subcoronary, (3) root inclusion

Following a renewal of interest in this procedure in the early 90's, long-term results of these procedures are beginning to emerge. It is now well established that autograft function may, in some patients, deteriorate over time eventually requiring replacement [6, 8, 12, 18, 19, 20, 21, 22]. Concerns surfaced lately regarding the ability of the isolated, unsupported pulmonary root to withstand the systemic circulation over time and resist progressive dilatation, threatening valve competence [22, 23], and leading to an unexpected increased rate of reoperation beginning around 7 to 8 years after the initial operation[24, 25, 26]. In a recently published meta-analysis, Takkenberg et al. have summarized the prevalence of structural and non-structural valve deterioration [27], reoperations and other major events observed in large studies of patients operated with the Ross procedure [25]. The incidence of autograft structural or non-structural valve deterioration in the published large studies averages at 0.78%/year (95% CI: 0.43 – 1.40) whereas the incidence of right sided homograft structural or non-structural valve deterioration is approximately 0.55%/year (95% CI: 0.26 – 1.17).

1.4 Research on the modes of autograft failure of the Ross procedure

After the realization of this potential, significant research has been conducted regarding the mode of autograft failure after the Ross procedure. Early autograft failure is often attributed to technical errors, as was the case with the technically demanding and difficult to reproduce subcoronary technique [14]. The introduction of the root replacement technique [15] seems to ameliorate early autograft failure, however reports of progressive autograft dilatation [8, 21, 28, 29] and subsequent late autograft failure have recently emerged [18, 21].

Understanding the modes of autograft failure after the Ross procedure, many groups have employed modified techniques or autograft reinforcement to correct abnormalities in the aortic root area and thus prevent anatomic mismatch [28, 29], or to stabilize parts of the aortic annulus prone to dilatation [16, 17, 22, 30]. However this long term impact of reinforcements on the autograft function and durability remains largely unknown.

1.5 The present study

The main focus of the present study was to unveil the effect of such reinforcement procedures on autograft function using data from the large patient population of the German-Dutch Ross Registry. The presence of two different techniques in the Ross Registry (subcoronary and root replacement) presents a challenge for this analysis, mainly because the evolution of the native aortic root pathology hosting a subcoronary implant is very different than the evolution of the freestanding pulmonary autograft root technique, and as such, reinforcement techniques might play different roles and serve different purposes in each of these techniques.

2. Patients and Methods

2.1 Study population and operative data

The analysis was performed using data from the German-Dutch Ross Registry. The registry includes data from 12 departments of cardiac surgery in Germany and The Netherlands since 1988.

Follow-up data from each center were entered in the database and a systematic prospective registry was started in January 2002 (*Clinical trial ID NCT 00708409*). The employed surgical technique was according to the surgeon's preference, with more or less each center having adopted the one or the other technique. The operative technique (subcoronary / root replacement) was specific for each institution and remained the same throughout the time period of the study. The vast majority of subcoronary procedures were performed in one center. In the root replacement technique, one center performed no reinforcement procedures at all, whereas the incidence of prophylactically performed reinforcement procedures increased with time in all other centers performing the root replacement Ross procedure. Thirty patient operated with the root inclusion technique were included in the subcoronary group, to create a group with all native root preserving procedures.

A total of 1335 patients were entered in the registry as of January 2008. The patients' preoperative characteristics as well as operative technique and presence or absence of reinforcement are summarized in **Table 1 page 11,** and **Table 2 page 12**, respectively. In brief, the patient population consists of young patients, with either normal or slightly reduced left ventricular. It is important to note that in this study, patients with tricuspid and bicuspid aortic valves where included, in contrast to a belief shared by some groups in the literature that the Ross procedure in the setting of the aortic valve is not advisable. In terms of intraoperative characteristics **(Table 2, page 12)**, the root replacement technique requires a longer duration of cardiopulmonary bypass and aortic cross clamp time (p<0.01 for subcoronary vs. root replacement groups) and results in larger early postoperative aortic annulus diameters and z-values as expressed (p<0.0001 for subcoronary vs. root replacement groups).

	Total Group	SC+R	SC−R	Root+R	Root−R
No. of patients	1335	152	485	443	255
Mean age±SD	43.5±12.0	44.9±10.6	45.1±11.8	44.4±11.5	38±12.2*
Range	16 to 70.5	16.7 to 65.6	16.3 to 70.5	16.1 to 67.7	16 to 65.4
<20	50 (3.7)	2 (1.3)	12 (2.5)	17 (3.8)	19 (7.4)*
20 to 40	443 (33.2)	48 (31.6)	147 (30.3)	128 (28.9)	120 (47.1)*
41 to 60	765 (57.3)	95 (62.5)	282 (58.1)	276 (62.3)	112 (43.9)*
>60	77 (5.8)	7 (4.6)	44 (9.1)	22 (5.0)	4 (1.6)*
Gender					
Male	1013 (75.9)	128 (84.2)	365 (75.3)	331 (74.7)	189 (74.1)*
Female	322 (24.1)	24 (15.8)	120 (24.7)	112 (25.3)	66 (25.9)*
LV ejection fraction					
>50%	1034 (77.4)	136 (89.5)	392 (80.8)	316 (71.3)	190 (74.5)
26–49%	141 (10.6)	12 (7.9)	52 (10.7)	43 (9.7)	34 (13.3)*
<25%	5 (0.4)	2 (1.3)	1 (0.2)	2 (0.5)	0 (0)
Unknown	155 (11.6)	2 (1.3)	40 (8.3)	82 (18.5)	31 (12.2)*
Predominant aortic hemodynamics†					
Stenosis	283 (21.5)	15 (10.0)	98 (20.4)	111 (25.8)	59 (23.3)*
Regurgitation	381 (29.0)	43 (28.9)	142 (29.5)	123 (28.5)	73 (28.8)
Mixed lesion	650 (49.5)	91 (61.1)	241 (50.1)	197 (45.7)	121 (47.8)*
Aortic valve morphology					
Nonbicuspid	460 (34.5)	17 (11.2)	173 (35.7)	162 (36.6)	108 (42.4)*
Bicuspid	820 (61.4)	133 (87.5)	291 (60)	259 (58.5)	137 (53.7)*
Other	55 (4.1)	2 (1.3)	21 (4.3)	22 (4.9)	10 (3.9)
Previous aortic valve interventions	98 (7.3)	9 (5.9)	16 (3.3)	36 (8.1)	37 (14.5)*

Absolute values (±SD). Relative values (in %) in brackets.

SC indicates subcoronary implantation technique; Root, root replacement technique; +/−R, with/without reinforcement; LV, left ventricle.

*P<0.01.

†Prosthetic valve dysfunction and acute endocarditis not included.

Table 1. Demographics and preoperative characteristics of the patient population

	Total Group	SC+R	SC−R	Root+R	Root−R
No. of patients	1335	152	485	443	255
Cardiopulmonary bypass time, mean±SD, min	189.8±45.4	215.8±39.5	207.4±32.8	163.2±37.3	191.4±56.2*
Range, min	71 to 685	71 to 345	81 to 433	95 to 372	71 to 685
Cross clamp time, mean±SD, min	150.5±35.4	182.2±40.2	167.1±30.1	130.9±24.9	136.2±28.2*
Range, min	38 to 293	43 to 293	65 to 273	79 to 258	38 to 238
Circulatory Arrest, n	48 (3.6)	34 (22.4)	0 (0)	12 (2.7)	2 (0.8)*
Additional procedures					
None	758 (56.8)	39 (25.7)	329 (67.8)	209 (47.2)	181 (71.0)*
Ascending aorta replacement	233 (17.5)	80 (52.6)	0 (0)	153 (34.5)	0 (0)
Ascending aorta reconstruction	162 (12.1)	18 (11.8)	65 (13.4)	48 (10.8)	31 (12.2)
Valve intervention other than aortic	48 (3.6)	9 (5.9)	27 (5.6)	6 (1.4)	6 (2.4)*
CABG	79 (5.9)	6 (4.0)	19 (3.9)	36 (8.1)	18 (7.1)*
LV Outflow Tract Enlargement	50 (3.7)	14 (9.2)	34 (7)	3 (0.7)	5 (2.0)*
Other	37 (2.7)	1 (0.7)	30 (6.2)	4 (0.9)	2 (0.8)*
Autograft reinforcement					
Annulus	514 (38.5)	93 (61.2)	0 (0)	421 (95)	0 (0)
Sinotubular junction	259 (19.4)	91 (59.9)	0 (0)	168 (37.9)	0 (0)
Annulus and sinotubular junction	180 (13.4)	33 (21.7)	0 (0)	147 (33.1)	0 (0)
Early postoperative z-value (aortic annulus)	0.4±2.1	−0.5±1.7	−0.6±1.7	1.4±1.5	1.7±2.5†
Clinical course <30 days					
In-hospital death	15 (1.1)	2 (1.3)	7 (1.4)	3 (0.7)	3 (1.2)
Reoperation on autograft	6 (0.4)	2 (1.3)	1 (0.2)	3 (0.7)	0 (0)
Reoperation on homograft	0 (0)				

Absolute values (±SD).

SC indicates subcoronary implantation technique; Root, root replacement technique; +/−R, with/without reinforcement; CABG, coronary artery bypass grafting.

*$P<0.01$, †$P<0.0001$ between SC and Root groups.

Table 2. Operative data and postoperative course

All indications for surgery were in line with the ACC/AHA guidelines [31]. In the majority of institutions, the presence of markedly reduced left ventricular function, extensive coronary artery disease, connective tissue or active rheumatic disorders, severe deformation of the aortic root anatomy or structural defects of the pulmonary valve as well as intractable systemic hypertension were considered contraindications for the Ross procedure [12, 30, 32].

As reinforcement procedure was regarded any additional procedure performed at the aortic annulus, sinotubular junction or both. Usually, at the level of the annulus, a 4-mm wide strip of pericardium, Dacron or a 2/0 Gore-Tex® suture was placed between donor and recipient tissues in order to stabilize or to prevent dilatation. In the root replacement group, reinforcement with mainly a Dacron strip was used in the majority of patients in the last 8 years. In the subcoronary group, as reinforcement, a 2/0 Gore-Tex® suture was incorporated in the annulus suture line **(Figure 2, page 13)**, if the annulus diameter exceeded 28 – 30 mm as measured prior to autograft implantation.

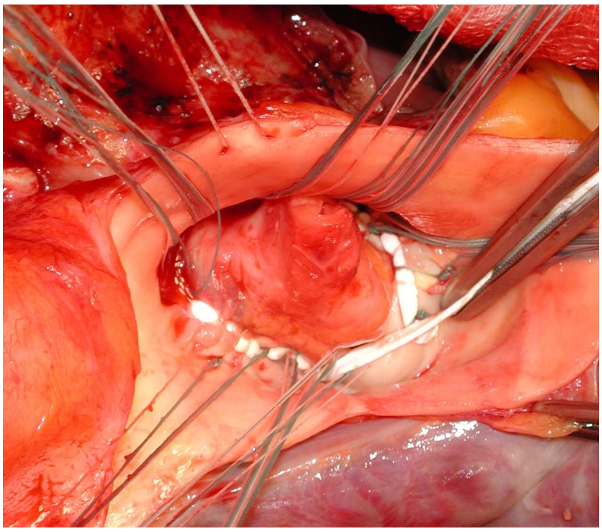

Figure 2. A 2-0 Gore-Tex® reinforcement suture is placed between donor and recipient tissues in order to stabilize or to prevent dilatation.

In the root replacement group, autograft reinforcement consisted also of an additional second suture line fixating circumferentially the remnants of the wall of the native aortic root to the autograft, 4 mm distal to the proximal suture line. In both techniques, reinforcement of the sinotubular junction was performed by suturing a Dacron prosthesis directly distal to the commissures, if an ascending aorta replacement was indicated.

Written informed consent was obtained from all patients. The study was approved by the ethics committee of the medical faculty of the University of Lübeck (No. 08-030).

2.2 Clinical and echocardiographic follow up

Clinical and echocardiographic follow-up was performed at discharge and on a yearly basis. The echocardiographic data acquisition protocol of the registry was standardized in all centers. Autograft dimensions were measured at four levels (annulus, sinus of Valsalva, sinotubular junction, proximal ascending aorta) as described by Roman et al [33]: (1) *annulus* at the level of the autograft leaflet hinges, (2) *sinus of Valsalva* at the largest anteroposterior diameter, (3) *sinotubular junction* at the distal rim of the sinuses of Valsalva, and (4) *the proximal ascending aorta* 2 cm above the sinotubular junction.

The degree of aortic regurgitation was assessed by multiple techniques with the parasternal long-axis and apical 5-chamber view. Pulsed wave Doppler and color flow Doppler imaging were used for mapping the left ventricular outflow tract, including determination of the ratio of jet height to left ventricular outflow tract height. Continuous Doppler imaging was applied to measure the deceleration slope and pressure half-time of the autograft regurgitation jet. Aortic regurgitation was graded with the use of standard criteria in a majority of the examinations [34]. Because this is a multicenter study, the final decision of autograft regurgitation (AR) grading was left to the decision of the responsible echocardiographer's preference and experience, and regurgitation severity was reported on a scale of grade 0 to 4 [34]. Trace (trivial) aortic insufficiency defined as a very tiny regurgitation jet in early diastole near the detection limit, was included in the analysis as grade 0.5. Mean duration of follow-up was 6.09 ± 3.97 years (median 5.6 years; range 0.01 – 19.2 years; 8205 patient-years). Follow-up completeness was 93 %. The 7% missing follow up visits were evenly distributed across the groups. Classification of the mode of valve failure has been performed according to the latest guidelines for reporting outcome after valve interventions [27]. All indications for autograft reoperations were in accordance to the ACC/AHA guidelines [31]. In two patients sub-valvular aortic aneurysms were the primary indication for reoperation.

2.3 Statistical analysis

Frequencies are presented as absolute numbers and percentages. Continuous data are expressed as mean ± standard deviation (SD). Patients were classified according to the operative technique (SC, Root) and the presence (+R) or absence (-R) of R. Comparisons between the groups were performed using the Mann-Whitney *U* test and the Fisher's exact test. Actuarial estimates of survival and freedom from autograft reoperation were accomplished with Kaplan-Meier methods. Survival curves were compared using the log-rank test (SPSS 11.0 for Windows, SPSS Inc., Chicago, IL). The Cox model was used to assess the consistency of treatment effect by testing for interactions between the type of surgery (technique and presence of autograft reinforcement) and prespecified baseline characteristics. In order to identify predictive variables for shorter time to autograft re-operation, we first performed a univariate analyses by using the Cox proportional hazard regression model. Multivariable Cox proportional hazard models were used to confirm whether differences between the operative groups persisted in the presence of pre-operative variables. The presence of interactions and the proportionality of hazards assumption was checked for the final model including operative group and significant pre-operative variables. The following factors were analyzed as potential risk factors for autograft re-operation due to structural and non-structural failure (infective endocarditis as a re-operation indication in 8 patients was excluded): age, gender, year of surgery, predominant aortic hemodynamics, hypertension, previous aortic valve intervention, presence of bicuspid aortic valve, operative technique and presence of reinforcement procedures.

2.3.1 The problem of analyzing serial echocardiographic measurements: Reporting without distorting

The statistical analysis of serial echocardiographic measurement in large patient populations is complicated by several factors: echocardiographic information is obtained at different time points, follow up appointments may be missed, valve function is variable over time, there is significant inter- and intraobserver variability and the use of different equipment may affect the measurement. The most frequently used method of analyzing and reporting serial echocardiographic measurement is the Kaplan-Meier method. However there are several concerns when utilizing this methodology in large patient registries.

First, as a concept the Kaplan-Meier method considers each event as irreversible, while the severity of valvular dysfunction or the aortic dimensions are very often variable overtime. Therefore, by regarding each measurement as irreversible, the Kaplan-Meier method underestimates the freedom from valvular dysfunction and inserts a significant bias when reporting the time point at which the valvular dysfunction progressed. The second problem with the Kaplan-Meier method is that it regards time as a continuous variable, which this is not the case when analyzing echocardiographic measurements over time. In the Kaplan-Meier function, every measurement is extrapolated and analyzed as if it is to hold true or stable until the time of the next examination. This inserts a bias a significant bias regarding the development of measurement over time in the case of missed follow up visits or changes in follow up schedules, something that is very frequently encountered in large registries.

Both factors mentioned above may play a minor role when analyzing small patient groups over a short period of time, and as such the Kaplan-Meier method has been utilized in analyses of small patient groups despite these known limitations. However in large patient populations, biased extrapolations of measurements accumulate fast, a fact that eventually renders the analysis and more importantly the interpretation of the results problematic. Thus in the case of the present study these factors prohibit the use of the Kaplan-Meier method, and the analysis and reporting of our results in an accurate way presents a major challenge.

2.3.2 Use of novel statistical methodology for the analysis and interpretation of the data

To study the autograft valve function with time, a hierarchical multilevel modeling technique was used according to the novel approach described by Takkenberg [35], which is now endorsed and recommended in the latest *Guidelines for reporting outcome after heart valve interventions [27]*. The echocardiographic data of 2 or more echocardiographic observations per patient were analyzed using a hierarchical multilevel linear model (MLWin 2.0; Centre for Multilevel Modeling, London, UK). This model provides a linear regression line with an *intercept* and *slope* for each individual patient and it estimates the mean intercept and slope across patients (**Figure 3, page 18**). This methodology allows for the severity of the valvular dysfunction or the various measurements (i.e. aortic root dimensions) to be treated as variable over time. Moreover this technique can account for missed or postponed appointments, since for every patient, all available past, present and future information is taken into consideration in order to analyze and evaluate the outcome for every patient and for the whole group all together. For every patient and for the whole population, a regression line is being fitted to identify the progression of the measured variable.

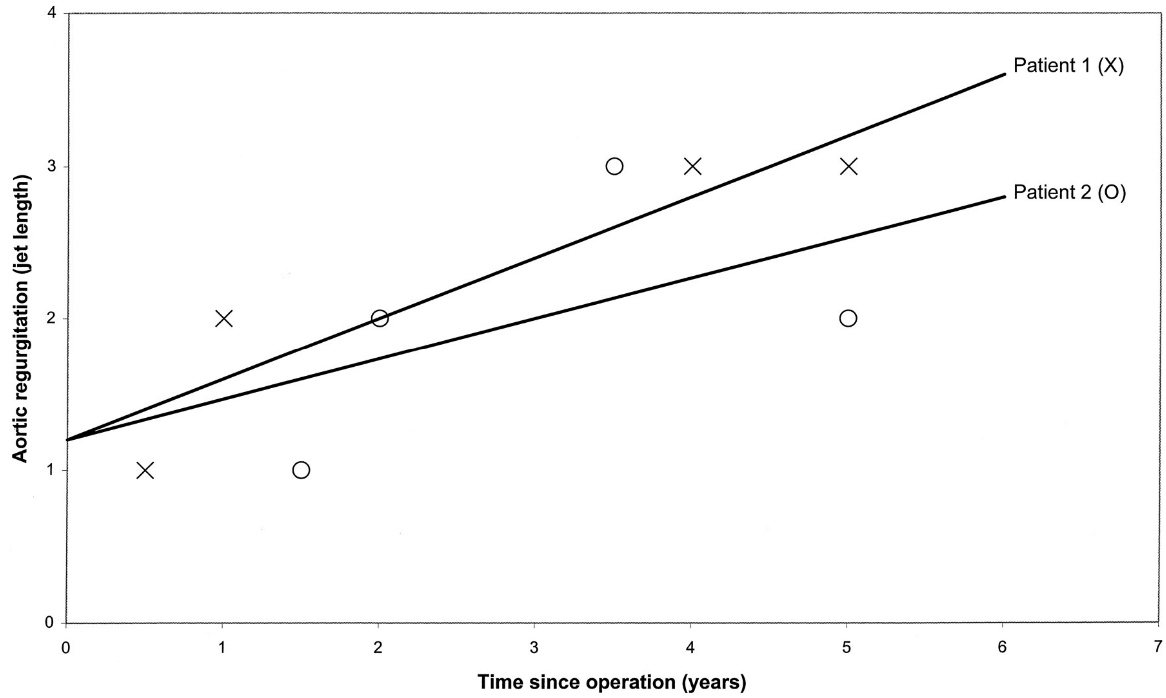

Figure 3. Analyzing serial echocardiographic measurements to examine the development of aortic regurgitation over time

The intercept and slope are assumed to vary randomly for the different patients. The intercept corresponds to the notional value at the time of surgery; the slope represents the annual progression of the measurement. The intercept and slopes provided represent the mean values across the population or subgroups throughout the period of the study, and should not be extrapolated beyond this. Statistical analysis of initial fitting and the influence of covariables were performed. The following covariables were used: age, gender, arterial hypertension (medically treated), bicuspid valve disease, preoperative valvular hemodynamics (regurgitation, stenosis, combined lesion), surgical technique (Root versus SC), autograft reoperation, previous aortic valve interventions, interventions at the annular level, and replacement of the ascending aorta.

Since this is a multicenter study, it reflects the daily practice of the Registry's sites, nevertheless the uniformity of the preoperative data is not warranted, and may have an influence in the statistical evaluation of the results. In an attempt to neutralize this center specific influence, we integrated in all analyses presented herein a center variable, allowing for the effect which the different centers may have to the results of this study. This model was applied to analyze AR and aortic root dimensions over time, as well as AR as a function of aortic root dimensions for the surgical subgroups Root and SC and subgroups with and without R. For the small subgroup of 30 patients operated with root inclusion technique, separate estimation of the AR development and AR dimensions over time was also performed.

3. Results

3.1 Clinical outcome and autograft reoperations

The duration of follow-up differed significantly between the groups with and without reinforcement procedures in both techniques (subcoronary, root replacement), with the reinforced groups having a shorter follow-up duration. This is due to the fact that reinforcement procedures were implemented mainly in the last 6-8 years.

The incidence of all cause, as well as cardiac related mortality was low in this series. In a total of 8205 patient years, 16 cardiac related deaths were observed with a linearized occurrence rate of 0.19%/year **(Table 3, page 20).** Overall cumulative survival was 94.6% (95% CI 92.8–96.4%) at 10 years.

	Total	SC+R	SC−R	Root+R	Root−R	P
No. of patients	1335	152	485	443	255	
Follow-up, y	6.09±3.97	3.31±2.37	6.44±3.56	5.06±3.07	9.08±4.84	*
All cause mortality	35 (2.6)	1 (0.7)	19 (3.9)	8 (1.8)	7 (2.7)	
Cardiac death	16 (1.2)	0 (0)	7 (1.4)	3 (0.7)	6 (2.4)	
Valve related mortality	12 (0.9)	0 (0)	5 (1)	2 (0.5)	5 (2.0)	
Other	19 (1.4)	1 (0.7)	12 (2.5)	5 (1.1)	1 (0.4)	
Reoperation						
Autograft	67 (5)	4 2.6)	18 (3.7)	11 (2.5)	34 (13.3)	*
SVD	18 (1.4)	4 (2.6)	10 (2.1)	3 (0.7)	1 (0.4)	
nSVD	41 (3.1)	0 (0)	2 (0.4)	7 (1.6)	32 (12.6)	*
Endocarditis	8 (0.6)	0 (0)	6 (1.2)	1 (0.2)	1 (0.4)	
Homograft	31 (2.3)	4 (2.6)	12 (2.5)	6 (1.4)	9 (3.5)	
SVD	19 (1.4)	1 (0.7)	3 (0.6)	6 (1.4)	9 (3.5)	*
nSVD	3 (0.2)	1 (0.7)	2 (0.4)	0 (0)	0 (0)	
Endocarditis	9 (0.7)	2 (1.3)	7 (1.4)	0 (0)	0 (0)	

SC indicates subcoronary implantation technique; Root, root replacement technique; +/−R, with/without reinforcement; SVD, structural valve deterioration; nSVD, nonstructural valve deterioration.
*$P<0.01$.

Table 3. Survey on mortality and reoperations

As a total, 67 autograft reoperations were observed (linearized occurrence rate 0.82%/year). Non-structural valve deterioration was the primary cause of failure (61.2% of all autograft reoperations). Structural valve deterioration and endocarditis accounted for 26.9% and 11.9% of all autograft reoperations respectively.

As a first observation, the root replacement technique group had significantly more reoperation than the subcoronary technique, and when allowing for the presence of reinforcement procedures, the root replacement group without reinforcement accounted for 56% of all reoperations in the study population.

When studying the modes of autograft failure in each technique significant conclusion can be made. In the root replacement technique the main mode of failure appears to be non structural valve deterioration (91% of all reoperations in the root replacement group), mainly in the form of autograft dilatation. On the contrary, in the subcoronary group the main mode of failure appears to be structural valve deterioration (88% of all reoperation in the subcoronary group).

Freedom from autograft reoperation (with the exclusion of 8 patients operated for infective endocarditis [27]) was 96.8% (95% CI 95.5–99.0%) at 5 and 89.6% (95% CI 86.1–93.0%) at 10 years. When allowing for technique and presence of R, the SC and the Root+R revealed a significantly better freedom from reoperation at 10 years in comparison to Root-R (94.2% (95% CI 90.4–97.9 %) and 93.2% (95% CI 88.2–98.2%) vs. 88.3% (95% CI 76.5–90.1%) respectively, p=0.001; **Figure 4, page 22**).

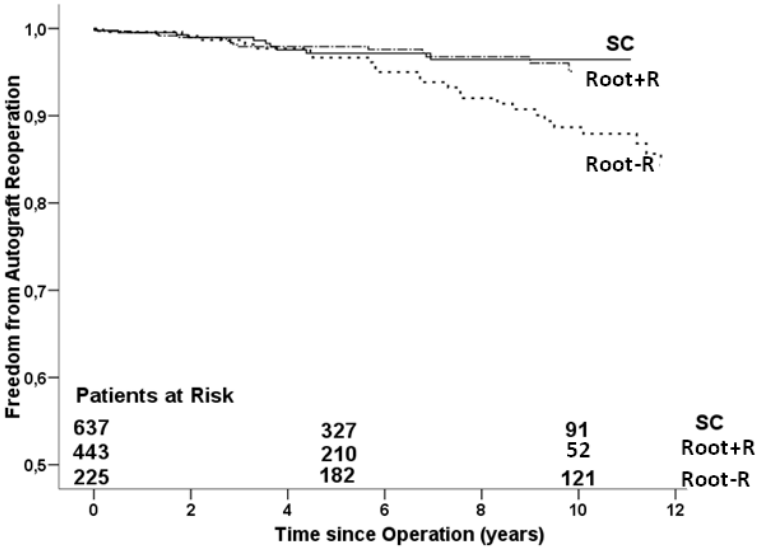

Figure 4. Estimated freedom from autograft reoperation comparing the surgical subgroubs subcoronary implantation (SC), root replacement with root reinforcement (Root+R) and root replacement without root (Root-R) reinforcement (log rank p=0.001)

Autograft reoperation rates were significantly higher in Root-R group in comparison with Root+R, SC-R, SC+R groups (12.5% vs. 2.3%, 2.6%, 2.5%, respectively, p<0.0001). The Root-R group accounted for 55.9% of all reoperations.

Taking into consideration the time of autograft failure, the patients at risk at every time point, and the surgical technique (as well as the presence of autograft reinforcement) we calculated the instantaneous risk for reoperation throughout the study period. This is depicted in **Figure 5 page 23** (due to the low numbers of reoperations in the reinforced subcoronary group, the subcoronary group is depicted as a total). While the risk for reoperation is constant with time on the subcoronary and root replacement with reinforcement groups, this is not the case with the root replacement group without reinforcements. In the latter group, autograft failures accumulate with time and the risk for reoperation rises exponentially 5-6 years postoperatively.

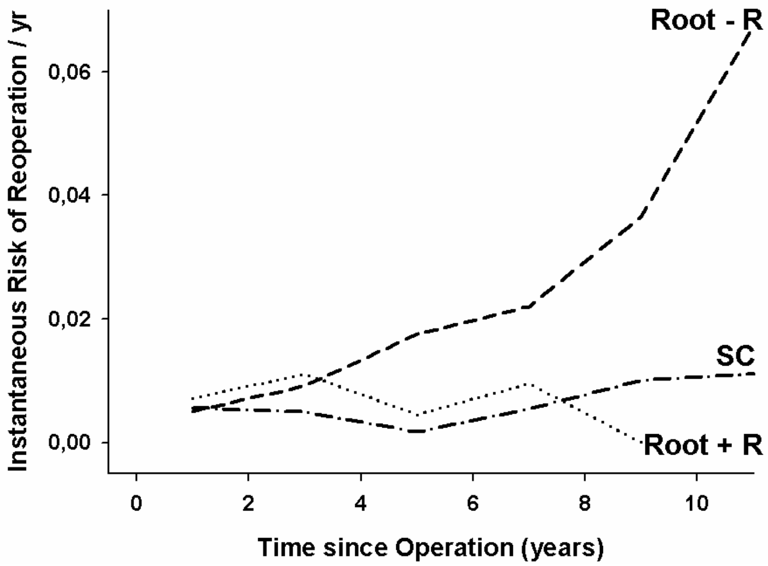

Figure 5. Instantaneous hazard for autograft reoperation per year for the surgical subgroups subcoronary implantation (SC), root replacement with root interventions (Root+R) and root replacement without root interventions (Root-R).

In an attempt to identify potential predictors for autograft failure the multivariable Cox proportional hazard model was employed. The model showed strong evidence that among the four operative groups, patients operated with the root technique without the use of reinforcement techniques tend to have shorter times to re-operation (hazard ratio 3.007, 95% CI: 1.52–5.96; p=0.0016). The same model was utilized to investigate the influence of preoperative variable on autograft failure and eventual reoperation. Of all preoperative variables studied, only the presence of preoperative aortic regurgitation was identified as a predictor for reoperation (hazard ratio 2.33, 95%CI: 1.29-4.24; p=0.0054). When combining the above models the significance of the root replacement technique without reinforcement and the presence of preoperative aortic regurgitation as predictors for autograft failure and reoperations persisted **(Table 4, page 24)**.

Predictor	Hazard Ratio (95% CI)	*P* Value
SC without reinforcement	Baseline	
Pre-op aortic regurgitation	2.121 (1.265 to 3.555)	0.0043
SC with reinforcement	1.966 (0.545 to 7.088)	0.30
Root without reinforcement	3.034 (1.533 to 6.002)	0.0014
Root with reinforcement	1.365 (0.585 to 3.182)	0.47

Table 4. Cox proportional hazard model for shorter time to reoperation

3.2 Development of aortic regurgitation over time

AR grade was found to develop approximately linearly with follow-up time. Based on 3803 measurements, the mean initial AR grade was 0.531 (±0.094) with an average increase of AR grade of 0.032 (±0.005) per year. There is significant evidence that AR increases with time (p<0.0001), but the amount of this increase is clinically not substantial.

In the current analysis, and allowing for a random centre effect, no difference between the Root and SC groups could be observed in terms of initial AR grade (0.519±0.10 vs. 0.543±0.101; p=0.71) and annual progression rate (0.035±0.007 vs. 0.029±0.006; p=0.49). Allowing for annulus reinforcement, in the SC groups, SC+R had higher initial AR grade compared to SC-R (0.667±0.112 vs. 0.491±0.100; p=0.0045), whereas no difference could be observed in the annual progression of AR (p=0.57, **Figure 6 page 25**).

In the Root subgroups, a higher initial AR grade in Root+R was observed (0.678±0.125 vs. 0.471±0.116; p=0.031), however in the presence of annulus R, AR remained stable for the first decade, in contrast to Root-R, in which AR increased at 6 fold rate compared to Root+R (Root-R: 0.067±0.010 AR grade/year vs. Root+R: -0.013±0.012 AR grade/year; p<0.001, **Figure 7 page 26**).

No significant differences between the SC and root inclusion technique could be observed in terms of initial AR grade and the annual increase of it. All models remained robust after adjusting for cofounding preoperative variables.

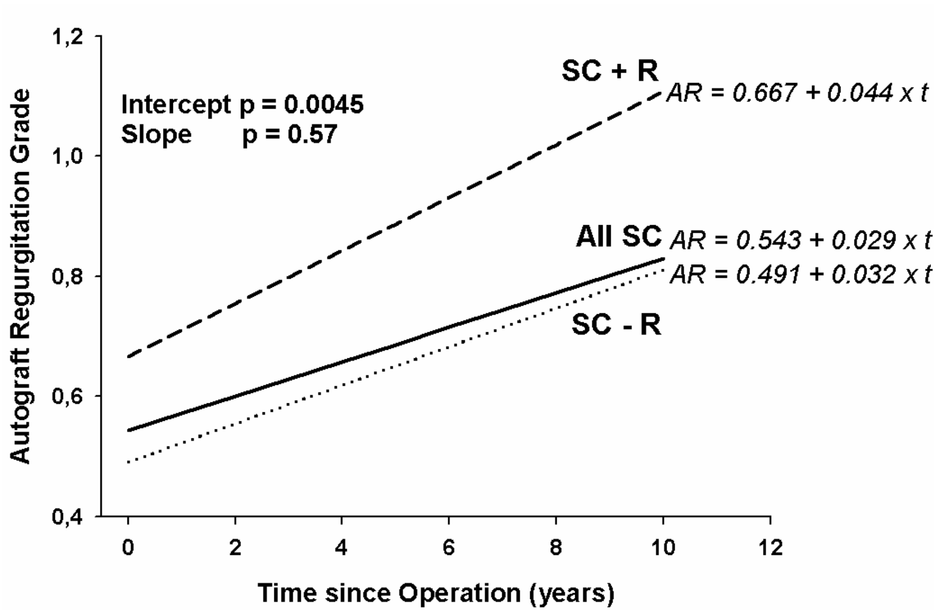

Figure 6. Autograft regurgitation with time in Ross patients with the subcoronary implantation technique (SC) with (SC+R) or without (SC–R) annulus reinforcement of the autograft.

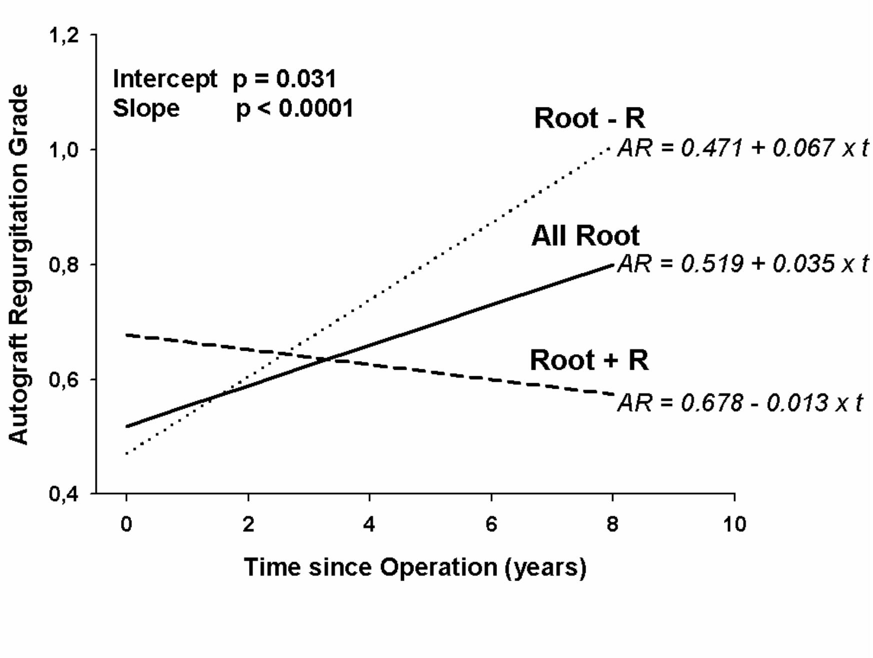

Figure 7. Autograft regurgitation with time in Ross patients with the root replacement technique (Root) with (Root+R) or without (Root–R) annulus reinforcement of the autograft.

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3.3 Change of autograft dimensions over time

An appropriate regression model to study diameter changes at the level of the aortic annulus, sinus and sinotubular junction with time was a linear model:

Diameter (time) = (Initial diameter ± SE) + (Annual increase of diameter ± SE) x time (yr).

3.3.1 Aortic annulus diameter

The initial aortic annulus dimensions were comparable between Root and SC (25.18±1.05 mm vs. 24.49±1.06 mm; p=0.26). The Root group dilated 3 times faster in the first decade (0.316±0.046 mm/year vs. 0.103±0.039 mm/year, p<0.0004). Taking the presence of annulus R into consideration, no difference could be observed between the Root subgroups. In SC, the presence of R led to higher initial annulus diameter (24.30±0.657 mm vs. 24.94±0.837 mm, p=0.008), the rate of annulus dilatation did not differ **(Figure 8 page 27)**.

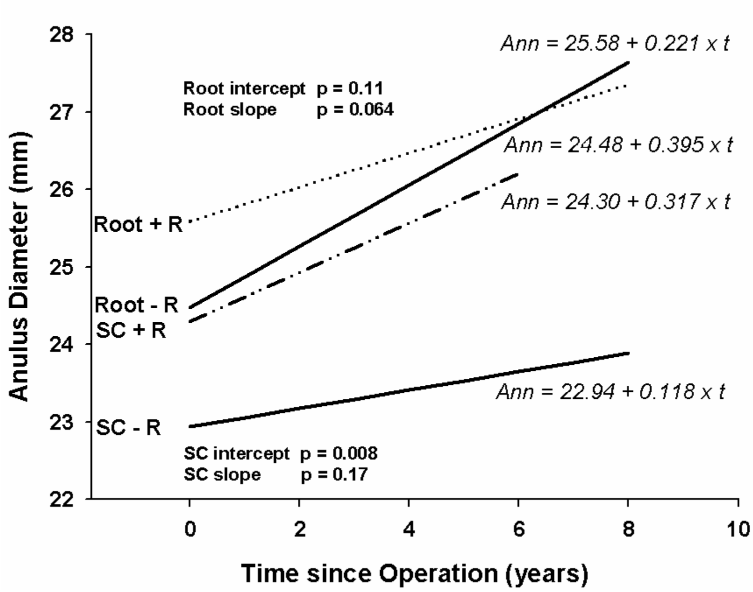

Figure 8. Multilevel modeling of the diameters of the autograft annulus.

3.3.2 Sinus of Valsalva diameter

The initial sinus of Valsalva dimensions were comparable between Root and SC (33.81±1.09 mm vs. 32.43±1.050 mm; p=0.10). During the first decade Root dilated 4 times faster than SC (0.259±0.063 mm vs. 0.064±0.039 mm/year respectively, p=0.008). No differences of the annual diameter increase within the subgroups of each technique could be observed when allowing for the presence of R **(Figure 9, page 28)**.

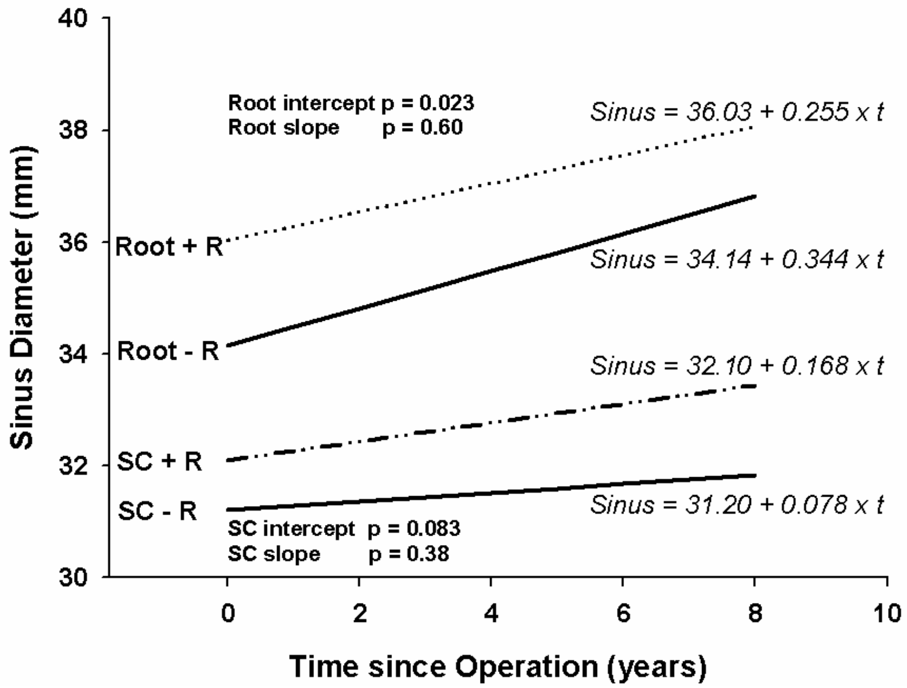

Figure 9. Multilevel modeling of the diameters of the sinuses of Valsalva.

3.3.3 Sinotubular junction diameter

A tendency towards lower initial diameters were observed in SC (29.54±1.58 vs. 31.11±1.59 mm; p=0.067), in the Root group the STJ tended to dilate almost 3 fold faster than in SC during the first decade (0.602±0.058 mm/year vs. 0.219±0.047 mm/year, p<0.0001) **(Figure 10, page 29)**. When allowing for STJ R, no differences between the subgroups of each technique (with or without STJ reinforcement) could be observed.

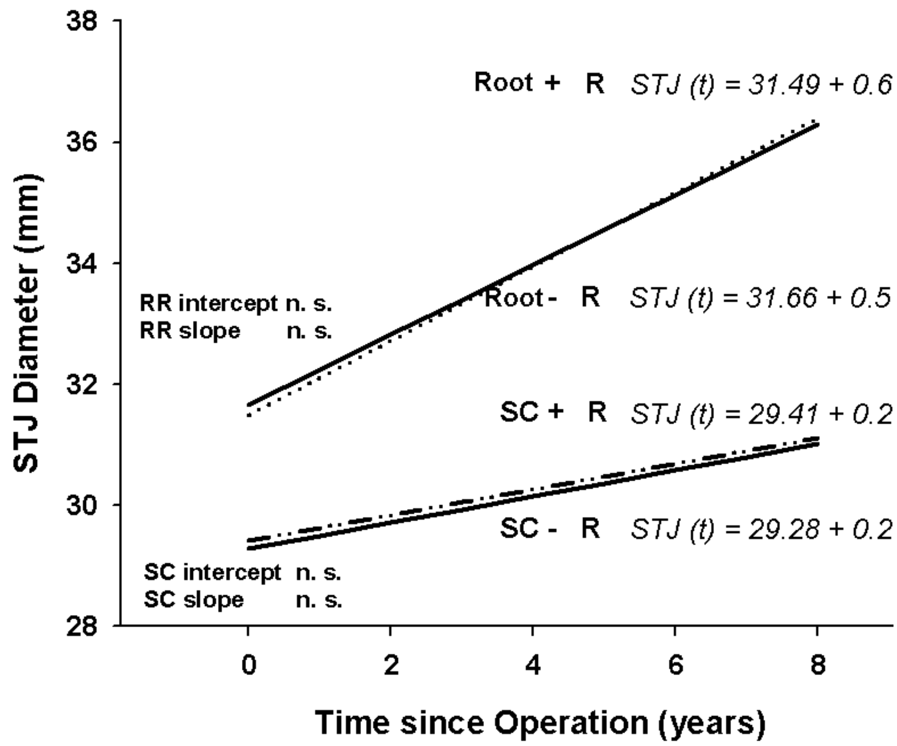

Figure 10. Multilevel modeling of the sinotubular junction diameters of the aortic root.

No significant differences between SC and root inclusion technique could be observed in terms of autograft dilatation over time. All models remained robust after adjusting for cofounding preoperative variables.

3.4 Change of dimensions and autograft regurgitation

The Root technique resulted in wider range of annulus and STJ diameters and a trend towards a higher slope of AR development with increasing diameters compared to the SC technique**.** AR development with increasing annulus or STJ diameters was lower in SC, which, together with the narrower range and lower slope of diameters in SC, makes this technique more robust against AR development with increasing annulus or STJ diameters. **(Figure 11, page 30 and Figure 12, page 30)**.

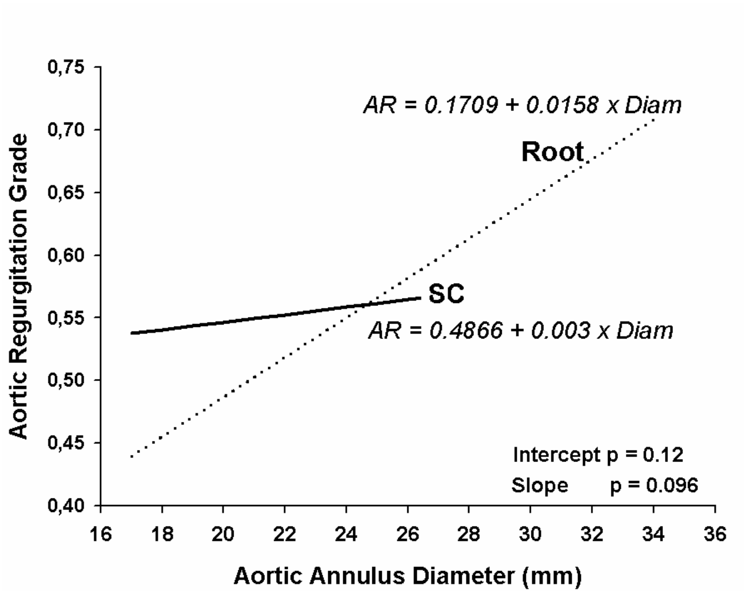

Figure 11. Multilevel modeling of the autograft regurgitation grade for the various postoperative aortic annulus diameters for the two surgical techniques.

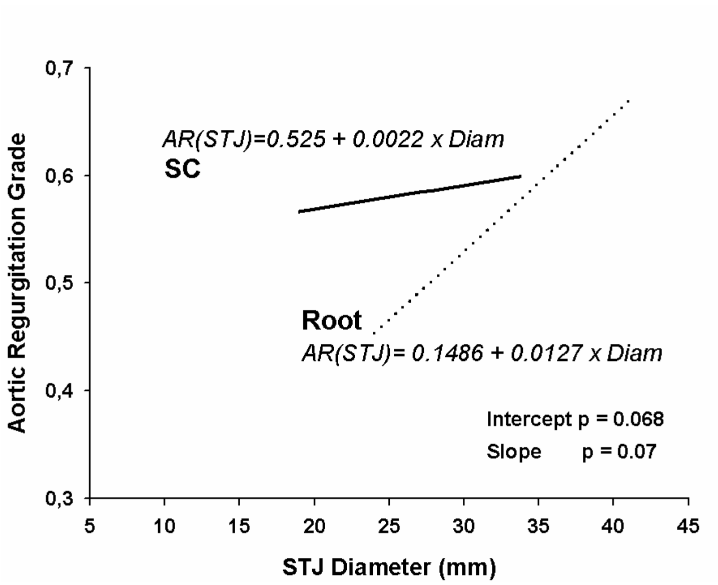

Figure 12. Multilevel modeling of the autograft regurgitation grade for the various postoperative sinotubular junction diameters for the two surgical techniques.

4. Discussion

The Ross procedure can be performed as an attractive alternative in selected patients, however various groups present mid-to-long term results indicating that the autograft function may deteriorate over time with the hazard of eventually mandating a reoperation [6, 8, 18, 20].

4.1 Previous studies

Significant research has been conducted regarding the mode of autograft failure after the Ross procedure. Early autograft failure is often attributed to technical errors, as was the case with the technically demanding and difficult to reproduce subcoronary technique [14]. The introduction of the root replacement technique [15] seems to ameliorate this early autograft failure, however reports of progressive autograft dilatation [8, 21, 28, 29] and subsequent late autograft failure have recently emerged [18, 21, 25].

Understanding the modes of autograft failure after the Ross procedure, many groups have employed modified techniques or R to correct abnormalities in the aortic root area and thus prevent anatomic mismatch [28, 29], or to stabilize parts of the aortic annulus prone to dilatation [16, 17, 22, 30]. The long term impact of R on the autograft function and durability remains largely unknown. Thus main focus of the present study was to unveil the effect of such R on autograft function. The presence of two different techniques in the Ross Registry (SC and Root) presents a challenge for this analysis, mainly because the evolution of the native aortic root pathology hosting a subcoronary implant is very different than the evolution of the freestanding pulmonary autograft root technique, and as such, reinforcement techniques might play different roles and serve different purposes in each of these techniques.

4.2 Present study

R in this study were performed in order to correct anatomical abnormalities or mismatch, or prophylactically in order to stabilize the aortic root and prevent postoperative autograft dilatation. The intention of the operating surgeon and the indication for performing R was determined by the operating surgeon at each institution.

4.2.1 Reoperation rates

Our main observation was that a significant proportion of the Root-R subgroup required reoperation in comparison to the three other subgroups. The Root-R group contributed 57% of all reoperations observed in the registry. The leading cause of reoperation in the Root group was non-structural valve deterioration, as defined in the latest guidelines[27] (91 % of all reoperations in this group) presenting in the form of autograft dilatation, whereas in the SC group 88% of all reoperations were attributed to structural valve deterioration [27], mainly as cusp prolapsed (patients reoperated due to endocarditis are excluded). The addition of R seemed to decrease reoperation rates due to non-structural valve deterioration in the Root+R group leading to reoperation rates similar to the SC technique. In the SC group, we could not show a significant impact of R on reoperation rates due to either structural or non-structural valve deterioration.

Autograft failure appears after the first 6-8 years in the Root-R group with an exponentially rising instantaneous hazard rate, while remaining stable throughout the observational period in the SC group. For the time period studied, the Root+R subgroup had similar reoperation risk rates as the SC group. This finding is in concordance to previous studies [36]. From our data it could be hypothesized that the larger the preoperative annulus dimensions, the lower the ability of the autograft to provide adequate leaflet coaptation with progressive root dilatation. In the Root group, R leads to smaller annulus diameters, and thus they may act prophylactically. It is however unknown if in the long term, reinforcement procedures prevent or postpone autograft function deterioration.

4.2.2 Autograft function

In this study we could not observe a significant difference with regards to AR development over time between the SC and the Root as overall groups. This is in contrast to a previous report of ours [8], where we found a significantly increased initial AR in the Root patients. This difference, however, could be attributed to the additional 321 patients (32% more than the 2006 report [8]) added to the registry in the last 2 years. Moreover, due to the non-uniformity of the preoperative data, in this analysis we allowed for a center effect to mitigate any systematic reporting error between the registry sites. The presence of R effectively prevented AR development over time in the Root group, whereas in the SC R had no effect on the AR increase, albeit for a greater initial AR. R in SC was implemented only in large annulus observed at operation to reduce or reshape the effective annular size to improve cusp coaptation. Here, the indication for R was not prophylactically but therapeutic.

4.2.3 Autograft dimensions

A consistent finding in this study is the larger initial postoperative aortic root diameters in patients undergoing R in both groups **(Figure 8, page 27; Figure 9, page 28; Figure 10, page 29),** although this does not always reach the level of statistical significance. Given however that, R are most likely to reduce the aortic root diameters, one can argue that R are often performed in order to treat underlying abnormalities, thus reducing aortic root dimension to restore the ideal anatomical relations. Although in our series R had a positive effect in terms of autograft durability, there are in the literature notable series of patients operated with the Root technique without R with excellent long term outcome [6, 19]. The effects of proper patient selection bias however cannot be ruled out since an – often intraoperative - selection of the appropriate patient-pathology is common in the setting of the Ross procedure. It may well be that in patients with an ideal aortic root pathology, a Root-R technique may have excellent outcome. In addition, it cannot be ruled out that special modifications on individual patient basis in very experienced hands can prevent postoperative dilatation without the need for R with synthetic material [19].

The SC technique was associated with significantly reduced rates of aortic root dilatation at all levels of the aortic root. In the Root technique, R did not influence the progressive autograft dilatation over time for the time period of the study. In this study we could observe an increased AR in patients with increased annulus and STJ diameters. Although a causal effect could not be established, this could be explained by the observational nature of this study and the increased reserve of the aortic root in terms of dilatation[37] that would lead to AR, and as such the time frame of this study could be insufficient to show that the AR increase is solely caused by root dilatation.

4.3 Limitations

The present study is a retrospective, non randomized study. The intention of the surgeon when performing R in SC was primarily to treat an underlying pathology, whereas in Root, R was mainly applied routinely as a part of root replacement. Early postoperative z-values are provided only for the aortic annulus, mainly due to the fact that large databases of normal values in the adult population do not exist for the other counterparts of the aortic root components. No technique to support the sinus of Valsalva was performed in this patient population. A further post hoc subgroup analysis to identify the most appropriate type of reinforcement material and or specific operative techniques was regarded statistically inappropriate due to the retrospective nature of this study. We believe that this should be performed in the setting of a prospective randomized trial. A small surgical subgroup operated with the root inclusion technique was included in the SC group. Sub analysis of key items (AR, autograft dimensions, reoperations) did not reveal any difference between the SC and the root inclusion technique group. A possible limitation may be the different follow-up times of the various study groups, with R in the Root, being mostly implemented in the last 8 years, having the shortest follow-up time. However the differences observed in outcome and autograft function were statistically and clinically significant for the time period studied.

4.4 Clinical implications

We can conclude that in patients undergoing the Ross procedure, autograft reinforcement procedures performed either prophylactically in order to prevent autograft dilatation, or therapeutically to correct an underlying a suboptimal anatomy, lead to lower development of AR over time. Surgical autograft reinforcement is able to reduce reoperation rates for autograft failure due to non-structural valve deterioration in the root replacement Ross procedure for the time period of this study. These procedures appear to be safe, present with good long term outcome and should strongly be taken into consideration.

5. Summary

Autograft reinforcement interventions (R) during the Ross procedure are intended to preserve autograft function and improve durability. Aim of this study is to evaluate this hypothesis.

1335 adult patients (mean age:43.5±12.0 years) underwent a Ross procedure (subcoronary, SC, n=637;root replacement, Root, n=698). 592 patients received R of the annulus, sinotubular junction, or both. Regular clinical and echocardiographic follow-up was performed (mean:6.09±3.97, range:0.01–19.2 years). Longitudinal assessment of autograft function with time was performed utilizing multilevel modeling techniques. The Root without R (Root-R) group was associated with a 6-times increased reoperation rate compared to Root with R (Root+R), SC with R (SC+R) and without R (SC-R) (12.9% vs. 2.3% vs. 2.5%. vs. 2,6% respectively, p<0.001). SC and Root groups had similar rate of aortic regurgitation (AR) development over time. Root+R patients had no progression of AR, whereas Root-R had 6 times higher AR development compared to Root+R. In SC, R had no remarkable effect on the annual AR progression. The SC technique was associated with lower rates of autograft dilatation at all levels of the aortic root compared to the Root techniques. R did not influence autograft dilatation rates in the Root group.

For the time period of the study surgical autograft stabilization techniques preserve autograft function and result in significantly lower reoperation rates. The non-reinforced Root was associated with significant adverse outcome. Therefore, surgical stabilization of the autograft is advisable to preserve long term autograft function, especially in the Root Ross procedure.

6. Zusammenfassung in deutscher Sprache

6.1 Einleitung

Der Einsatz der körpereigenen Pulmonalklappe zur Behandlung einer Erkrankung der Aortenklappe (Ross-Operation), erstmalig durchgeführt von Donald Ross im Jahre 1967[13], könnte die einzige Methode sein, welche, zumindest theoretisch, alle Vorteile eines autologen, biologischen Klappenersatzes hat. Bei der Ross-Operation wird die native Pulmonalklappe des Patienten entnommen und in Aortenklappenposition eingesetzt, während ein pulmonaler Homograft (Spenderklappe) in Pulmonalposition implantiert wird.

In den frühen 90er Jahren wurde das Interesse an dieser Methode erneut geweckt, so dass jetzt Langzeitergebnisse dieser Operationstechnik vorliegen. Es zeigt sich, dass bei einer Reihe an Patienten Struktur und Funktion der operierten Klappe sich so verändern, dass ein Ersatz dieser Klappe(n) erforderlich wird [6, 8, 12, 18, 19, 20, 21, 22].

Bei der Suche nach Ursachen für eine Klappendysfunktion entwickelten verschiedene Arbeitsgruppen zusätzliche chirurgische Methoden zur Stabilisierung des Autografts („Reinforcement“- R). Damit soll eine Korrektur der Aortenwurzelanatomie und ihre Stabilität im Langzeitverlauf angestrebt werden [28, 29], zusätzlich war eine Verstärkung des dilatationsanfälligen Annulus aortae beabsichtigt [16, 17, 22, 30]. Der Langzeiteffekt dieser Maßnahmen auf Funktion und Haltbarkeit des Autograftes ist jedoch weitgehend unbekannt.

Das Ziel der vorliegenden Arbeit ist, mit Hilfe der großen Patientenpopulation des Deutsch-Holländischen Ross-Registers die Auswirkungen von R auf die Funktion des Autograftes im Langzeitverlauf zu untersuchen.

6.2 Patienten und Methoden

Zur Analyse wurden Daten des Deutsch-Holländischen Ross-Registers aus 12 herzchirurgischen Abteilungen seit dem Jahr 1988 herangezogen. Bis Januar 2008 wurden 1335 Patienten in das Register aufgenommen. **Tabelle 1, Seite 11 und Table 2, Seite 12** enthalten die präoperativen Charakteristika der Patienten sowie die Besonderheiten der Operationstechniken (subkoronar, SC; Wurzelersatz, Root) mit (+R) bzw. ohne (-R) R.

Klinische und echokardiographische Verlaufsuntersuchungen wurden bei Entlassung sowie einmal jährlich durchgeführt. Die mittlere Dauer der Verlaufsbeobachtung betrug 6.09 ± 3.97 Jahre (Median 5.6 Jahre; 0.01–19.2 Jahre; 8205 Patientenjahre). Die Vollständigkeit der Datensätze betrug 93%.

Für den Vergleich zwischen den Gruppen wurden der Mann-Whitney *U*-Test und der Fisher`s Exact-Test herangezogen. Kaplan-Meier-Methoden dienten der Abschätzung der Überlebenswahrscheinlichkeit und der Freiheit von Autograft-Reoperationen. Überlebenskurven wurden mit Hilfe des log-rank-Tests (SPSS 11.0 for Windows, SPSS Inc., Chicago, IL) verglichen. Mit Hilfe des Cox-Modells wurden Interaktionen zwischen Art der Operation (OP-Technik und der Anwendung von Autograft-R) und verschiedenen präoperativen Charakteristika untersucht.

Um die Funktion des Autograftes in Abhängigkeit von der Zeit zu modellieren, wurde eine hierarchische Multilevel-Analysentechnik (sog. Mehrebenenanalyse) eingesetzt, die von den aktuellen *„Guidelines for reporting outcome after heart valve interventions“* [27] gefordert wird.

6.3 Ergebnisse

Die Anzahl an Autograft-Reoperationen bei strukturell und nicht strukturell bedingten Klappenfehlfunktionen waren in der Root-R Gruppe, verglichen mit den Gruppen

Root+R, SC-R und SC+R signifikant erhöht (12,5% vs. 2,3%, 2,6% bzw. 2,5%; p<0,0001). Die Root-R Gruppe enthält 55,9% aller Reoperationen (**Tabelle 3, Seite 20 und Abbildung 5, Seite 23**). Bei SC und Root+R war der Anteil an Reoperationen nach 10 Jahren verglichen mit der Root-R Gruppe signifikant niedriger (p=0.001).

Das multivariable Cox-Modell der vier Operationsgruppen zeigte, dass Patienten mit präoperativer Aortenregurgitation (AR) und Patienten, welche eine Operation mit Wurzelersatz, aber ohne Reinforcement erhalten haben, zu früheren Zeitpunkten reoperationspflichtig werden (**Tabelle 4, Seite 24**).

Der Schweregrad der AR nahm annähernd linear während der Nachbeobachtungszeit zu. Das auf 3803 Einzelmessungen basierende Gesamtmittel der initialen AR war 0,531 (±0,094) mit einem durchschnittlichen Anstieg des AR-Schweregrades von 0,032 (±0,005) pro Jahr. **Abbildung 6, Seite 25** und **Abbildung 7, Seite 26** zeigen die zeitlichen Entwicklungen der AR in den vier chirurgischen Untergruppen.

Die Entwicklung der Dimensionen des Aortenannulus über die Jahre ist in **Abbildung 8, Seite 27** dargestellt. Der Annulus der Gesamtgruppe mit Wurzelersatz dilatierte im Vergleich zur SC-Gruppe 3 mal schneller in der ersten Dekade (0,316±0,046 mm/Jahr vs. 0,103±0,039 mm/Jahr, p<0,0004). Vergleichbar nahmen die Dimensionen auf Höhe der Sinus Valsalvae in der Gesamtgruppe mit Wurzelersatz im Vergleich zur SC-Gruppe 4 mal schneller zu (0,259±0,063 mm/Jahr vs. 0,064±0,039 mm/Jahr, p=0.008; **Abbildung 9, Seite 28**), die Dimensionen des sinutubulären Übergangs (STJ) dilatierten bei größeren Ausgangswerten 3 mal schneller in der ersten Dekade (Wurzelersatzgruppe 0,602±0,058 mm/Jahr vs. SC 0,219±0,047 mm/Jahr, p<0,0001; **Abbildung 10, Seite 29**).

Bei der Wurzelersatz-Technik waren größere Spannweiten der Annulus- und STJ-Diametern auffällig. Mit zunehmendem Durchmesser war ein Trend zu einem steileren Anstieg des AR-Schweregrades zu verzeichnen. Die SC-Gruppe zeigte ein geringe Zunahme des AR-Schweregrades bei größeren Annulus- oder STJ-Diametern. Dies war assoziiert mit einer kleineren Spannweite der Diameter in der Gesamtgruppe und einem geringeren Anstieg der Diameter im zeitlichen Verlauf **(Abbildungen 11, Seite 30 und 12, Seite 30)**.

6.4 Diskussion

Der Einsatz von zusätzlichen chirurgischen Maßnahmen („reinforcement“) bei der Ross-Operation kann zur Korrektur einer pathologischen Aortenwurzelgeometrie beitragen oder aber als Prophylaxe dienen, um die Aortenwurzel im Langzeitverlauf zu stabilisieren und so einer gefürchteten Dilatation des Autograftes mit Funktionsbeeinträchtigung entgegen zu wirken.

Die wesentlichste Beobachtung der vorliegenden Arbeit war, dass Ross-Operationen als Wurzelersatz ohne Unterstützungsmaßnahmen zu einem signifikant höheren Anteil an Autograftfehlfunktionen führte mit der Notwendigkeit einer Reoperation (57 % aller Reoperationen des gesamten Registers). Hauptursache waren nicht-strukturelle Klappenveränderungen (87 % aller Reoperationen dieser Gruppe) in Form einer Autograft-Dilatation, während in der SC-Gruppe 63% aller Reoperationen auf strukturellen Klappenveränderungen, vorwiegend als Klappenprolaps, basierten. Die Anwendung von chirurgischen Unterstützungsmaßnahmen in der Wurzelersatz-Gruppe senkte den Anteil an Reoperationen, so dass Reoperationshäufigkeiten vergleichbar der SC-Gruppe erkennbar waren.

Die vorliegenden Daten unterstützen die häufig diskutierte Hypothese, dass vornehmlich zusätzliche Annulus-Interventionen zur Verkleinerung und Verstärkung dieser Ebene der Aortenwurzel führen und die Geometrie und Funktion des Autografts über viele Jahre erhalten. Bei komplettem Wurzelersatz werden die zusätzlichen Maßnahmen sowohl prophylaktisch (zur Verhinderung einer Dilatation) wie auch therapeutisch (zur Korrektur einer abnormen Geometrie) eingesetzt, während bei der SC-Technik Annulus-Maßnahmen praktisch ausschließlich mit therapeutischem Ziel Eingang fanden. Damit sollte effektiv eine zugrundeliegende Wurzelpathologie korrigiert werden, um die Ross-Operation überhaupt zu ermöglichen. Somit sind Vergleichbarkeit dieser Intervention zwischen den Operationsgruppen und ihre Interpretation nur bedingt möglich. So vermindern unterstützende Maßnahmen beim Wurzelersatz effektiv die Entwicklung einer AR, während in der SC-Gruppe kein wesentlicher Einfluss auf den Anstieg des AR-Schweregrades gesehen wurde. Offen muss auch bleiben, ob die zusätzlichen chirurgischen Maßnahmen eine Verschlechterung der Autograftfunktion im Langzeitverlauf verhindern oder lediglich aufschieben.

6.5 Schlussfolgerungen

Im untersuchten Zeitraum der Studie erhalten zusätzliche stabiliserende Maßnahmen bei der Ross-Operation die Geometrie und Funktion des Autografts aufrecht und führen zu so zu signifikant niedrigeren Reoperationsraten. Ein Wurzelersatz ohne Annulusstabilisierung führt nach 6 – 8 Jahren zu einer Wurzeldilatation mit rapid progredienter Autograftdysfunktion. Die chirurgische Stabilisierung des Autograftes bei der Wurzelersatztechnik ist daher ratsam, um die Funktion des Autograftes im Langzeitverlauf zu gewährleisten.

Appendix

A. References

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