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The Ross Procedure: Is it the Ideal Operation for the Young with Aortic Valve Disease?

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ABSTRACT

Background: Aortic valve prosthesis with adequate hemodynamic performance should allow more complete left ventricular mass regression and normalize left ventricular function. This possibly affects long-term prognosis after aortic valve replacement.

Objective: Assessment of hemodynamic performance of pulmonary autograft in the aortic position and the regression of left ventricular mass after the Ross procedure.

Methods: Between May 1995 and March 1996, 45 patients with mean age of 27.1 years underwent a Ross procedure. Doppler echocardiography and cardiac catheterization were performed on all patients before hospital discharge to evaluate the hemodynamic performance of auto- and homografts, as well as to evaluate left ventricular mass and function. Fourteen patients with follow-up longer than six months were submitted to dobutamine stress echocardiography to study the hemodynamic performance of auto- and homografts during exercise.

Results: Hospital mortality was 6%. After a mean follow-up of 12.8 months (1–23 months), there was one late sudden death. No valve-related event was observed during this period. Immediate and late hemodynamic performance of the pulmonary autografts were normal with an average mean gradient of 1.8 ± 0.6 mmHg and an average maximum instantaneous gradient of 2.9 ± 0.9 mmHg. Valvular insufficiency was insignificant. Even during exercise, gradients did not increase significantly with an average mean gradient of 4.3 ± 2.5 mmHg and an average maximum gradient of 10.4 ± 6.1 mmHg. Homografts used for right ventricular reconstruction showed excellent immediate hemodynamic performance. However, at late follow-up an increase in flow speed was observed with an average of mean gradient of 10 ± 7.1 mmHg at rest and 26 ± 13.3 mmHg during exercise. Left ventricular mass index dropped from 168 ± 46 g/m^2 preoperatively to 115 ± 32 g/m^2 six months after the operation. Left ventricular function was normal at rest and during exercise in the majority of patients.

Conclusion: Given the normal hemodynamic function of pulmonary autografts, the reduction of ventricular mass and normalization of left ventricular function, in addition to the excellent late follow-up of the patients, the Ross procedure is considered the operation of choice for young patients requiring aortic valve replacement.

INTRODUCTION

Adequate aortic valve prosthesis must, among other characteristics, have normal hemodynamic performance. This makes left ventricular repair easier, allowing a more complete regression of ventricular hypertrophy, with eventual normalization of the left ventricular mass and function. Thus, better functional ability may be achieved, decreasing morbidity and improving late survival [Krayenbuehl 1989, Krumholz 1995, Panidis 1984].

Despite all technological advances in the design of prosthesis and in the preservation of biological tissues, none of the conventional mechanical or biological prostheses display this characteristic. They are all, at least slightly stenotic, leaving residual gradients even at rest [Gray 1984, Khan 1990, Karpuz 1996, Kamachi 1985]. During physical exercise, the blood flow increase through the fixed orifice of these prostheses may be combined to greatly increased pressure gradients, thereby keeping the stimulation for the maintenance of a certain residual degree of ventricular hypertrophy [Barner 1994, Rothkopf 1979, Warwick 1990].

The use of a pulmonary autograft for aortic valve replacement (Ross operation) is very controversial [Ross

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Table 1. Clinical Data

	Observed	n	%
Valvular lesion	AoI	26	58
	AoS	6	14
	AoDL	13	28
Etiology	RD*	31	69
	Congenital	11	25
	Endocarditis	2	4
	Degenerative	1	2
NYHA functional class	I	4	8
	II	26	58
	III	15	34
	IV	0	0
Preoperative rhythm	Sinus	43	96
	Junctional	1	2
	AF	1	2
CTI	<0.50	9	20
	0.50–0.60	30	67
	>0.60	6	13
Operation	Primary	43	96
	Reoperation	2	4

n= number, % = percentage; AoI = aortic insufficiency; AoS= aortic stenosis; AoDL= aortic double lesion; RD= rheumatic disorder; AF = atrial fibrillation; CTI= cardiothoracic index; NYHA= New York Heart Association. *12 patients had combined mitral lesions.

1993]. Early and late results show that, once implanted correctly, pulmonary autograft has a better hemodynamic performance than any other kind of valvular graft, providing a better late survival rate with a minimal incidence of complications [Matsuki 1988, Ross 1988, Elkins 1992]. The disadvantages of this procedure include the size of the surgery, the need to place a prosthesis on the right ventricular outlet and difficulties in obtaining homografts [Oury 1993].

In this article, we report our two-year experience with the Ross procedure. Sequential clinical and hemodynamic evaluations (obtained from echocardiography and cardiac catheterization) were carried out with special attention to left ventricular mass regression. In order to further study the hemodynamic performance of autografts and left ventricular function, some patients underwent stress echocardiography with dobutamine to simulate intensive physical exercise conditions.

MATERIAL AND METHODS

From May 1995 to March 1996, 45 patients underwent aortic valve replacement by pulmonary autograft. Thirty-one were male and mean age was 27.1 ± 10.7 years (minimum = 9, maximum=50). Forty-three patients were Caucasian and two were black. Additional data are shown in Table 1 ◎.

All of the patients were evaluated before bidimensional Doppler echocardiography. In addition to providing data for diagnosis and surgical indication, echocardiography measured left ventricular systemic dimension (LVSD), left ventricular diastolic dimension (LVDD), left ventricular posterior wall thickness (PW), interventricular septal thickness (septum), left ventricular shortening percentage (%ΔD), and ejection fraction (EF). Thus, left ventricular mass (VM) and left ventricular mass index were calculated (VMI). These parameters were subsequently compared to early and late postoperative results (see Graph 1 ◎). Forty-two patients underwent cardiac catheterization preoperatively.

The operations were carried out by median sternotomy with the aid of extracorporeal circulation (ECC) with aortic and caval cannulation. Systemic moderate hypothermia at 32° C and myocardial protection with cold (4° C) blood cardioplegic solution were continuously used in the coronary ostia. Mean time of aortic clamping was 124 ± 24 min (69–175) and ECC was 167 ± 30 min (125–285).

Resection of the ascending aorta proximal segment, including the valve, was performed, leaving two fragments of aortic tissue surrounding the coronary orifice. The pulmonary trunk was distally sectioned next to its bifurcation, and proximally, in the right ventricular infundibulum, with particular care to avoid damaging the anterior interventricular artery or the first large septal branch.

Pulmonary autograft was implanted as a full replacement of the initial portion of the aorta in 44 cases and as a free graft inside the aorta in one case. Proximal anastomosis was performed with separate polyester 4-0 stitches and distal anastomosis with continuous polypropylene 4-0 suture. Coronary buttons were reimplanted in the autograft with continuous polypropylene 6-0 suture.

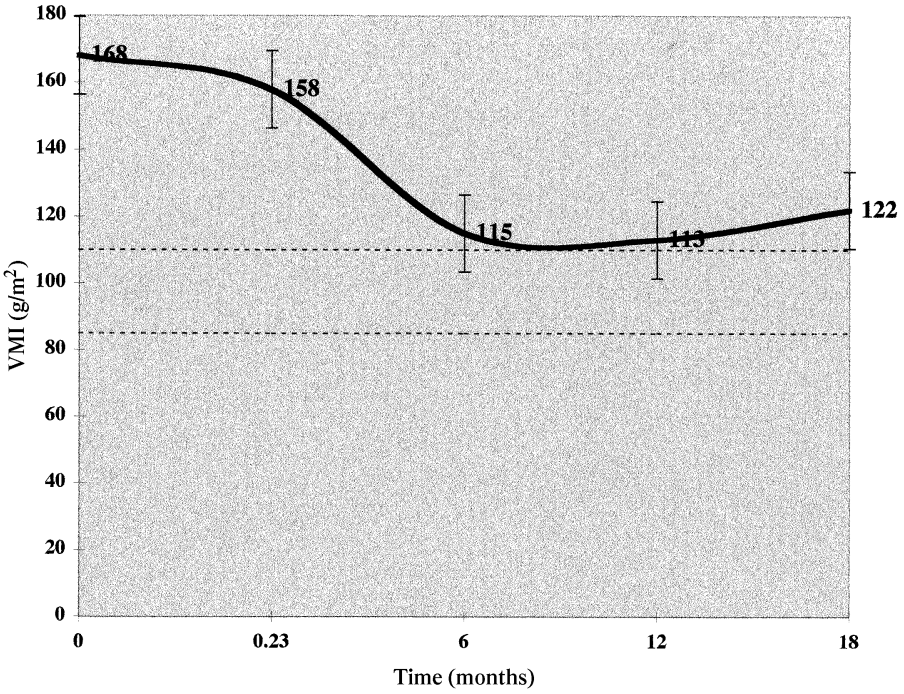
Procedures at the aortic ring or the ascending aorta were required to make the respective diameters compatible with the pulmonary autograft in 15 cases: enlargement of the aortic ring by simple incision (one case), enlargement of the ring by Manoughuian's technique (two cases), Konno procedure (one case), ring's attachment at the intercommissural triangle (four cases), external reduction of the aortic ring with bovine pericardial patch (one case), enlargement of the ascending aorta with bovine pericardial patch (one case), and reduction of the diameter of the ascending aorta by wedge resection of the wall (five cases).

The right ventricular outlet repair was done by pulmonary homografts (33 cases) or aortic grafts (12 cases) with proximal and distal continuous polypropylene 4-0 suture. In the earlier procedures the grafts were preserved in nutrient solution containing antibiotics (35 cases) and more recently, they were cryopreserved at –196° C in liquid nitrogen (ten cases).

Combined procedures included mitral commissurotomy, mitral plasty and myocardial revascularization, one at a time.

Early postoperative evaluation includes the analysis of hospital complications, cardiac auscultation and electrocardiographic tracings before hospital discharge (see Figure 1 ◎).

All of the patients underwent echocardiography and catheterization before hospital discharge. In the echocardiography, in addition to the parameters obtained preop-



Graph 1. Ventricular Mass Regression after Ross Procedure.

eratively, maximum instantaneous (Δp_{max}) and mean (Δp_m) gradients were recorded by the pulmonary autograft and the homograft of the right ventricular outlet. The regurgitation from these grafts was classified as none, insignificant, mild, moderate or severe, according to well-established echocardiographic standards [Edmunds 1988] (see Figure 2 ◎).

Peak gradients were calculated through auto- and homografts by cardiac catheterization. The severity of valve insufficiency was established and angiographic recordings were evaluated.

Fourteen patients followed-up for over six months underwent stress echocardiography with increasing dobutamine doses up to 40mg/kg body weight. Thus, sys-

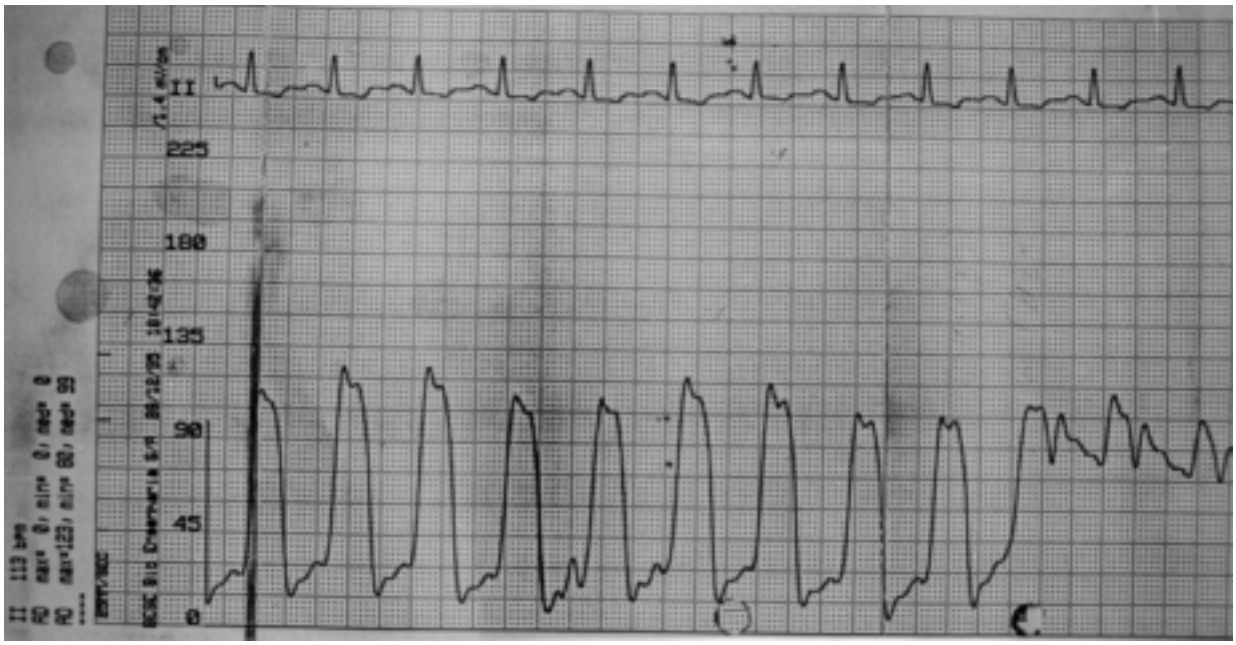


Figure 1. Sequential Left Ventricular and Aortic Pressure Curves in Early Hemodynamic Study after Ross Procedure.

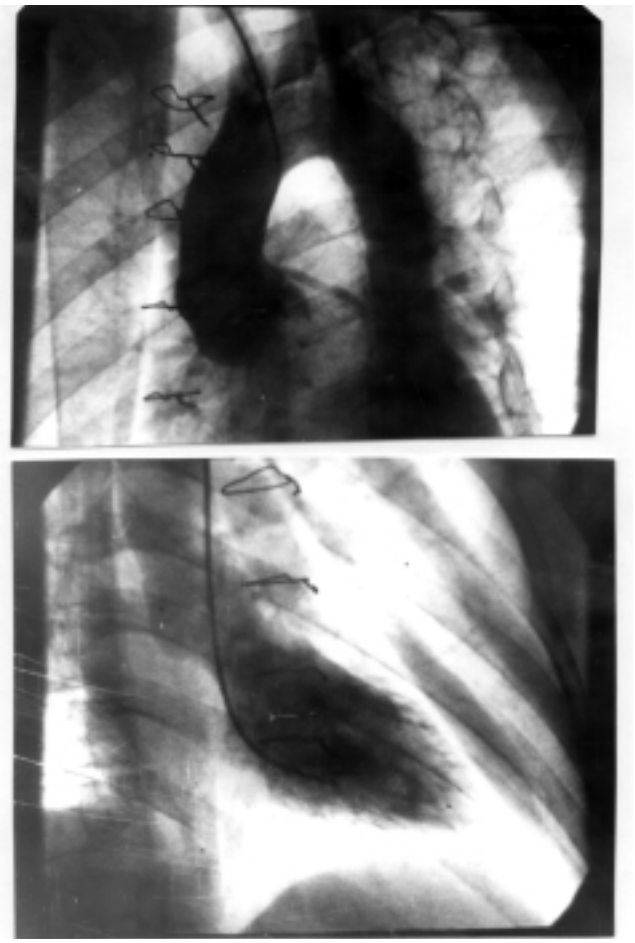


Figure 2. Left ventriculography and aortography in immediate Ross Procedure Follow-up.

tolic volume, cardiac output, Δp_{max}, Δp_m and flow effective areas (FEA) were calculated through the grafts at rest and with stress. For comparison, two patients with conventional prostheses (a bovine pericardial prosthesis and a St. Jude prosthesis), both with a nominal diameter of 23 mm, were submitted to the same stress protocol to establish a control.

All of the patients have had clinical review evaluations at our service or with their referring doctor, every six months. The evaluation of postoperative complications was carried out according to well established guidelines [Edmunds 1988].

RESULTS

There were three (6%) hospital deaths, all by left ventricular failure, caused by: angulation of the left coronary artery trunk, lesion of the first large septal branch, and inadequate myocardial protection, respectively.

In the remaining patients, the immediate postoperative follow-up was quite favorable. Two patients had moderate low output syndrome, and in one of the patients (a child) this was related to a probable rheumatic disease. One patient had mild transient mental disturbances, which resolved after 24 hours. No other significant complications were observed, and it must be emphasized that none of the patients required reoperation due to bleeding.

Table 2. Immediate Aortic Failure

Insufficiency	None	Insignificant	Mild	Moderate	Severe
Ao insufficiency (echo)	33	5	4	0	0
Ao insufficiency (cath)	37	3	2	0	0

echo= echocardiography; cath= cardiac catheterization

Diastolic murmur of insufficiency did not occur at any time. All of the patients were discharged from the hospital with sinus rhythm. Right bundle-branch block and hemiblock were each observed only once.

After a mean follow-up time of 12.8 months (range 1 to 23 months), 38 patients were in functional class I and three patients were in functional class II. There was a late death (sudden) in postoperative month two. No other late complications (thromboembolism, hemorrhage, endocarditis or primary valvular dysfunction) were observed. This results in a survival free from complications of 97.4% in 23 months (see Graph 2 ◎). [Note: Image references have been changed from the original version for clarity.]

Hemodynamic Evaluation of the Autografts

Adequate early hemodynamic performance of the autografts was evidenced by the low gradients observed by echocardiography and catheterization carried out prior to hospital discharge (see Table 2 ◎). Likewise, the incidence of valvular insufficiency was insignificant (see Table 3 ◎). Figure 1 shows LV and aortic sequential pressure curves in one of the patients and Figure 2 ◎ shows typical angiographic pictures of the LV and aorta postoperatively.

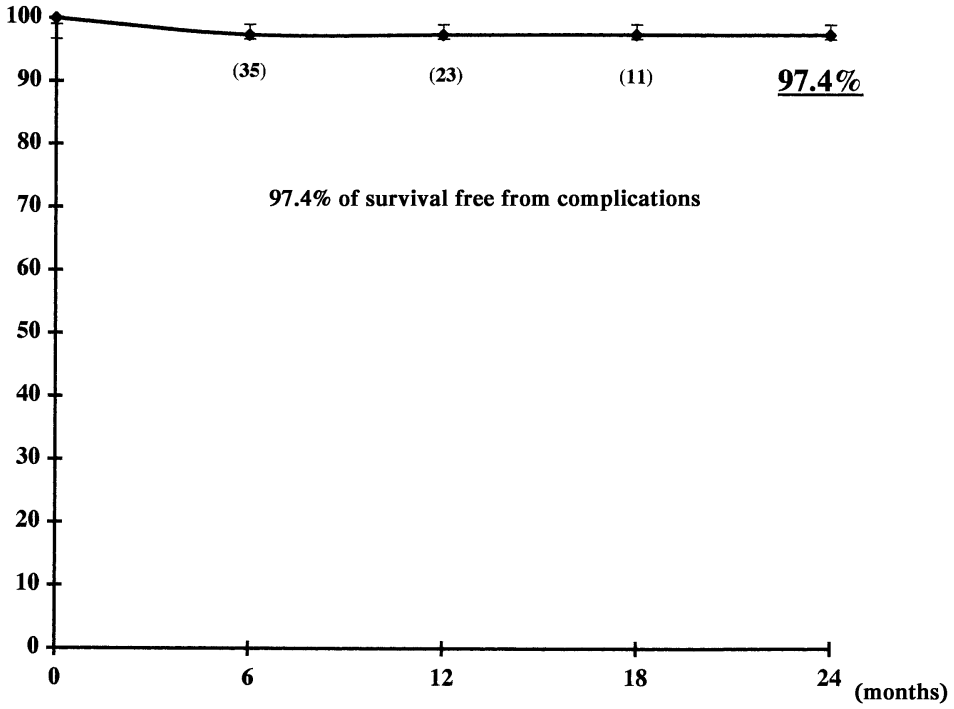
Sequential echocardiographic study in 27 patients showed that these results were maintained in all of the patients up to 23 months of follow-up. In some cases there was an even greater decrease in the gradients in the late follow-up. Worsening of valvular insufficiency was not observed.

In the 14 patients undergoing stress echocardiography with dobutamine, it was shown that even with a cardiac output 2.3 times greater than at rest, flow speed and con-

Table 3. Immediate Gradiants in Autografts

Gradiants	Mean ± SD(mmHg)	Range
Aortic Δp_{max}(echo)	2.9 ± 0.9	0 – 20
Aortic Δp_m(echo)	1.8 ± 0.6	0 – 11
Aortic Δp_{peak} (cath)	2.8 ± 1.2	0 – 18

SD= standard deviation; mmHg= millimeters of mercury; echo= echocardiography; cath= cardiac catheterization.

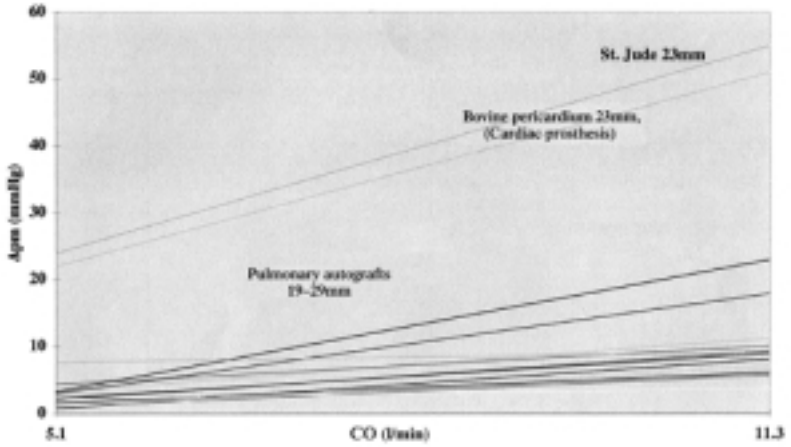


Graph 2. Actuarial Survival Curve Free from Complications after Ross Procedure.

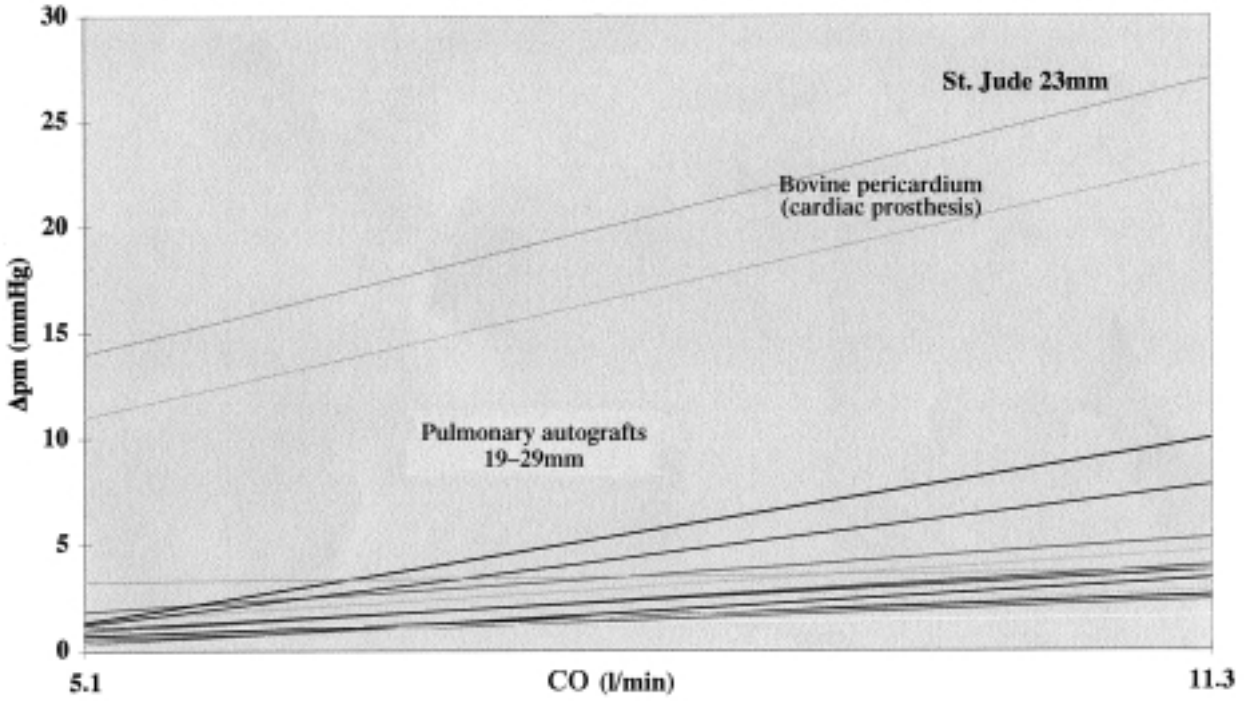
sequently, Δp_m and Δp_{max} did not significantly increase. These findings are similar to those of normal aortic valves. FEA values were close to normal. Valvular insufficiency as a result of drug-simulated exercise was not observed. Table 4 ◎ and Graphs 3 and 4 ◎ show these data.

Hemodynamic Evaluation of the Homografts

In the early follow-up, the hemodynamic performance of the homografts used for the repair of the right ventricular outlet was very satisfactory. Δp_{max} estimated by Doppler ranged from 0–17 mmHg (mean = 4.9 ± 0.9 mmHg) and by



Graph 3. Analysis of Δp_{max} at Rest and Exercise by Stress Echocardiography with Dobutamine.



Graph 4. Analysis of Dp_m at rest and exercise by Stress Echocardiography with Dobutamine.

catheterization from 0–15 mmHg (mean = 4.3 ± 1.4 mmHg). Significant valvular insufficiency was not observed.

In the late follow-up, increase in flow speed was observed through the homografts, recording Δp_m ranging from 2–28 mmHg (mean = 10 ± 7.1 mmHg) and Δp_{max} ranging from 3–37 mmHg (mean 14.7 ± 9.9 mmHg).

During echocardiography with dobutamine, flow speed increased proportionally to cardiac output, Δp_m ranged from 7–50 mmHg (mean = 26 ± 13.3 mmHg), and Δp_{max} ranged from 19–68 mmHg (mean = 36 ± 16.7 mmHg).

Although there was no direct correlation between the late gradients observed and the type and/or diameter of the homograft used, the two largest gradients were observed in homografts with diameter index lower than 12 mm/m^2 of body surface. Worsening of valvular insufficiency was not observed.

Table 4. Pulmonary Autograft Gradients in Stress Echocadiography with Dobutamine

Parameters	Rest	Exercise
CO (l/min)	5.1 ± 1.3	11.3 ± 4.0
Δp_m (mmHg)	1.02 ± 0.8	4.3 ± 2.5
Δp_{max} (mmHg)	2.2 ± 1.9	10.4 ± 6.1
FEA (cm)	3.23 ± 1.1	3.37 ± 1.3

Δp_{max}= maximum instantaneous gradient; Δp_m= mean gradient; FEA= flow effective area

Evaluation of Ventricular Mass and Function

A 6% decrease of the left ventricular mass was observed in the early follow-up as compared to preoperative values. There was a significant decrease of the ventricular mass (17%-41%, mean = 32%) late postoperatively, with values very close to normal after about 6 months of follow-up (see Graph 1). The decrease in left ventricular mass was due initially to the decrease in LV diastolic dimension and later, to a decrease in the thickness of LV septal and posterior wall. These combined to an even greater decrease of LV diastolic dimension (see Table 5 ◎).

Maintenance or improvement of LV contractile function was also observed, with normal values for %ΔD and EF in 23 patients and slightly decreased values in four cases (see Table 5 ◎).

During stress echocardiography, a normal response of the ventricular function was observed, with the expected increase in heart rate, hyperkinesia of all LV walls and an EF increase in 13 patients. The test of one patient who experienced ventricular bigeminy with a dobutamine dose of 20 µg/kg/min was discontinued.

DISCUSSION

The choice of the best aortic valve replacement for young patients is still troublesome; it depends on the specific characteristics of each prosthesis as well as on factors related to the patient. Such factors include the etiology of the valvular dysfunction, socio-economic status, left ven-

Table 5. Left Ventricular Mass and Function

Parameters	Preoperative	Immediate Postoperative	6 Months	12 Months	18 Months
LVDD	63 ± 10.1	52.9 ± 9.3	51.6 ± 6.7	51.2 ± 7.4	52.6 ± 5.06
PW (mm)	10.7 ± 1.6	12.4 ± 2.2	10.2 ± 1.7	9.4 ±1.3	10.4 ± 1.6
Septum (mm)	10.9 ± 1.5	12.9 ± 1.8	10.4 ± 2.0	9.1 ± 1.3	10.5 ± 2.2
MVC (g)	304 ± 46	285 ± 49	208 ± 42	204 ± 13	211 ± 21
VMI (g/m^2)	168 ± 46	158 ± 49	115 ± 42	113 ± 23	122 ± 25
% ΔD	37 ± 8.8	26.4 ± 5.8	38 ± 5.9	41 ± 4.4	42 ± 5.9
EF	66 ±7.4	52 ± 9.7	65 ± 9.21	63 ± 13.4	69 ±11.3

LVDD= left ventricular diastolic diameter; PW= posterior wall thickness; Septum = interventricular septum thickness; VMI= ventricular mass index; %ΔD= shortening percentage; EF= ejection fraction

tricular function, cardiac rhythm, dimension of the aortic ring, presence of associated lesions, and others [Jones 1994].

The use of biologic prosthesis in this group of patients may require future reoperations, whereas with the mechanical prosthesis the chance of thromboembolic events is very high, if the difficulties in obtaining a correct anticoagulation is taken into consideration. The use of a pulmonary autograft is very attractive, because it is durable and associated with a small incidence of late complications [Elkins 1994, Matsuki 1988, Ross 1988].

Even though it is a more complex operation from a technical point of view, our results show that the Ross procedure may be carried out with an acceptable mortality rate, comparable to those reported by other authors and by the International Record of Ross procedures [Elkins 1992, Kumar 1993, Pacifico 1994, Oury 1993].

Likewise, even with longer aortic clamping times and ECC required to carry out this procedure, postoperative morbidity was minimal. This indicates that the continuous perfusion of cold blood cardioplegic solution in the coronary ostia provided good myocardial preservation.

Short- and medium-term results have shown to be very promising. Survival was 97% after a maximum follow-up time of 23 months, and no late prosthesis-related complications were observed. Most of the patients are in NYHA functional class I, none of the patients is using anticoagulant or antiplatelet agents, and in several cases, all cardiovascular drugs were discontinued a few months after the operation. In our opinion, when comparing prosthesis procedures the quality of life after Ross procedure is better, although this is a subjective parameter.

The hemodynamic performances of the current biological and mechanical prostheses are satisfactory; however, all have residual gradients, even at rest [Gray 1984, Kamachi 1985, Karpuz 1996, Khan 1990]. In a few patients having small initial portions of the aorta, the use of smaller prosthesis may be associated with very high residual gradients. Brux et al. [Brux 1996] reported that Carbomedics prostheses at less than 12 mm/m^2 of body surface are usually highly stenotic. This can be observed with other kinds of prostheses, as reported by several authors [Barner 1994, Brux 1996, Karpuz 1996, Juanatey 1996, Mahon 1996, Warwick 1990].

Pulmonary autografts allow the substitution of the aortic valve with normalization of the hemodynamic performance [David 1996, Ross 1994, Ross 1991]. From the technical viewpoint this involves, whenever required, the accurate modeling of the initial portions of the aorta, so that the geometric relationship of the valve and pulmonary trunk is compatible [David 1996]. In our series of patients, these measurements are carefully carried out, and associated procedures are frequently performed to increase or decrease the initial portion of the aorta and/or ascending aorta. The effectiveness of these maneuvers may be observed by coronary cineangiography in the immediate follow-up period, with normal angiographic images of the LV outlet, "aortic valve" and ascending aorta.

By means of cardiac catheterization and echocardiography, it was observed that immediate hemodynamic function of the pulmonary autograft in aortic position may eventually be considered "normal". Mean and maximum gradients were insignificant, with flow speed similar to the normal aortic valve. Calculated FEA also showed values within the normal range, considerably higher than those reported for other kinds of prostheses [Barner 1994, Kamachi 1985, Karpuz 1996, Rothkopf 1979]. Similar data have been reported by other authors [Elkins 1992, Kouchoukos 1994].

In the late postoperative period the gradients remained the same, or even lower in some cases; this decrease is probably due to the regression of ventricular hypertrophy of the LV outlet and to the remodeling of the pulmonary autograft with reabsorption of the RV outlet musculature of the graft while it is implanted. A similar condition has been reported for porcine prosthesis without support [Rizzo 1996].

More recently, some authors [Juanatey 1996, Mahon 1996, Warwick 1990] have shown that prosthesis with satisfactory hemodynamic performance at rest can be inadequate during exercise. This would explain, at least partially, the lower physical ability of some patients with aortic valvular prosthesis. Likewise, this suboptimal hemodynamic condition probably maintains stimulation for left ventricular hypertrophy, which is in turn, related to late complications, such as congestive heart failure, ventricular arrhythmias and sudden death [Krayenbuehl 1989, Krumholz 1995, Panidis 1984, Rizzo 1996].

Using high dobutamine doses of up to 40 mg/kg, it was possible to simulate physical exercise conditions, increasing the cardiac output to 2.3 of the baseline value. Even in conditions of increased cardiac output, flow speed and consequently, the gradients showed physiological action through the autografts, and did not increase significantly. This response is different from those observed in the conventional "control" prostheses which showed significant gradients during stress (see Graphs 3 and 4 ◎).

Rizzo et al. [Rizzo 1996] reported significant decrease in the left ventricular mass in patients with porcine aortic prosthesis without support and related it to good hemodynamic performance. Frazier et al. [Frazier 1996] recently showed that left ventricular mass reduction after aortic valve replacement was greater when prostheses with better hemodynamic performance were used. In this study, we also observed a significant reduction of left ventricular mass, with even lower values than those reported by the authors above. Although a direct comparison of the results is not possible, we believe the greater reduction observed in this study is due to the performance of pulmonary autografts.

The normal ventricular response during stress observed in this study is very promising and can explain the excellent functional ability shown by the patients and, eventually, have important implications in the late prognosis.

Cryopreserved pulmonary homografts and/or aortic grafts are considered the best option for the repair of RV outlet [Bando 1995, Kay 1985]. In the initial phase of our experience, we used homografts preserved in nutrient solution at 4°C. More recently, we developed the technique for the cryopreservation of valvular homografts, making possible the use of cryopreserved homografts.

According to Matsuki et al. [Matsuki 1988], the need of reoperation due to graft dysfunction after Ross operation was 9.2% after a 20-year follow-up. According to Bando et al. [Bando 1995], pulmonary homografts have a lower trend to calcification and degeneration than the aortic grafts, because they have a smaller amount of elastin in their walls.

In our experience, the hemodynamic function of right-sided homografts was very satisfactory in the immediate follow-up. However, four patients showed maximum instantaneous gradients higher than 20 mmHg in the late evaluation. These data are similar to the experience of David et al. [David 1996], who reported mean gradients of 20–28 mmHg in 18% for patients with over one year of follow-up. Likewise, Kay and Ross [Kay 1985], reported gradients of 24 mmHg in homografts with six years of follow-up. The explanation for this is the immunologic reaction of the receptor with development of fibrosis on the graft wall and decrease of the caliber. This was confirmed by angiography in one of our cases. Valvular function was, however, preserved and the condition was stabilized. Valvular replacement was not required in most of the patients. Therefore, the use of calibrated grafts and the removal of the adventitia are recommended to decrease the immunologic reaction [Ross 1994].

DISCUSSION

Ross operation can be carried out with low mortality and minimal morbidity. Normal hemodynamic performance of the pulmonary autografts in aortic position was demonstrated by cardiac catheterization and echocardiography at rest and during exercise. A significant left ventricular mass reduction was observed with values close to normal around postoperative month six. Ventricular function was also normal at rest and during exercise in most of the patients.

For the reconstruction of the right ventricular outlet, the use of cryopreserved homografts with large calibers is recommended to avoid eventual residual gradients late postoperatively.

In the face of the excellent hemodynamic results and late survival with virtually no morbidity, the Ross procedure is considered the ideal procedure for young aortic patients.

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