Aortic homograft improves hemodynamic performance and clinical outcome at mid-term follow-up

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Key words:
Aortic valve; Aortic valve replacement; Left ventricular mass; Valvular surgery.

Background. **Cryopreserved homograft is currently considered an excellent choice for the replacement of a diseased aortic valve in adults and it is the first choice for 1 with aortic endocarditis. The aim of this study was to analyze our single institution experience with the cryopreserved aortic homograft by a mid-term follow-up.**

Methods. **Between December 1996 and September 2003, 46 consecutive patients underwent aortic valve replacement using either aortic or pulmonary homograft. The risk profile was moderate-to-high, with a mean log EuroSCORE of 6.33 ± 5.12. All patients were periodically evaluated at discharge, at 6 and 12 months, and yearly thereafter, to assess their clinical status and hemodynamic performance by comparing the ejection fraction, left ventricular mass index, mean gradient, effective orifice area index, and diastolic and systolic eccentricity indexes.**

Results. **The overall 30-day mortality was 4.3%. At univariate analysis, the significant determinants of in-hospital mortality were: aortic dissection ($p < 0.001$), urgent operation ($p = 0.05$) and a log EuroSCORE > 10 ($p = 0.05$). At multivariate analysis no independent predictors of in-hospital mortality were found. At 5 years of follow-up, the survival was 91.3 ± 5.0%, the freedom from reoperation was 95.8 ± 4.1%, the freedom from sudden death was 96.1 ± 3.9%, and the freedom from readmission for congestive heart failure was 94.1 ± 3.1%. In patients with either prevalent aortic valve stenosis or prevalent aortic valve insufficiency, a significant improvement in the preoperative ejection fraction during follow-up (49 ± 4 vs 51 ± 7%; $F = 5.1$, $p = 0.04$ and 50 ± 10 vs 53 ± 10%; $F = 7.1$, $p = 0.01$ respectively) and a significant reduction in the preoperative left ventricular mass index during follow-up (202 ± 55 vs 143 ± 28 g/m^2; $F = 7.5$, $p = 0.008$ and 177 ± 49 vs 138 ± 24 g/m^2; $F = 8.8$, $p < 0.001$) were recorded.**

Conclusions. **Replacement of the diseased aortic valve with a cryopreserved homograft offers clear advantages in terms of excellent hemodynamics, resistance to infection, and a negligible incidence of postoperative regurgitation.**

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Introduction

Cryopreserved homograft is currently considered an excellent choice for the replacement of the diseased aortic valve in adults[1-3]. It does not necessitate anticoagulation, has excellent hemodynamics, is resistant to infection, and has a negligible incidence of acute failure[4]. The cryopreserved homograft is particularly useful in patients with extensive endocarditis[4-6]. It is a relatively simple, easily reproducible operation both when used as a subcoronary implant and as a root replacement[7].

O'Brien et al.[8] developed the technique currently used for homograft cryopreservation, and rendered it readily available for use by many surgeons. This technique has resulted in significant improvements in long-term performance of the homograft valves, because of the preserved viability of the component cells of the homograft[9].

The purpose of this article was to analyze, by means of a mid-term clinical and echocardiographic functional evaluation, our single institution experience with the cryopreserved aortic homograft used for aortic replacement.

Methods

Patient profile. Between December 1996 and September 2003, 46 consecutive patients underwent aortic valve replacement (AVR) alone or associated with aortic root replacement either using an aortic or pulmonary homograft. Twenty-seven patients (58.7%) underwent concomitant coronary artery bypass grafting and mitral operations. They represented 4.3% of all the aor-

tic procedures performed in our department. The main preoperative characteristics of the patients are summarized in table I.

The inclusion criteria for replacement of the diseased aortic valve with a cryopreserved homograft were endocarditis, younger and active patients, patients with a small aortic annulus, patient's request and homograft availability.

Homograft data. Aortic homograft valves were harvested under sterile conditions from cardiac transplant recipients and from beating heart or non-beating heart donors aged between 18 and 65 years. Harvesting of the heart was performed within 12 hours of circulatory arrest. After harvesting, the valves were decontaminated by incubation in medium with an antibiotic mixture for 5 hours at 37°C. Thereafter, valves were cryopreserved in medium containing 10% dimethylsulfoxide frozen at a controlled rate of -1°C/min up to -100°C and stored on the vapor of liquid nitrogen (-150 to -196°C). All tissues were cryopreserved within 50 hours of circulatory arrest of the donor. All donors were seronegative for human immunodeficiency virus, hepatitis B surface and core antigen, *Cytomegalovirus* or *Treponema pallidum*. For implantation, ABO compatibility was not required.

Surgical technique. All operations were performed through a standard median sternotomy under moderately hypothermic cardiopulmonary bypass. Myocardial protection was achieved with injection of cold blood cardioplegia into the aortic root or coronary ostia and retrograde cardioplegia through the coronary sinus.

In case of subcoronary insertion, the aorta was transected about 1 cm above the coronary orifices and the original valve, including all calcific or inflammatory remnants, was completely excised. The annulus and the sino-tubular junction were measured. The homograft was trimmed of all its attached right ventricular muscle and scalloped close to the base of the cups. Three primary interrupted (4-0) sutures were passed through the nadir of the excised cusp remnants and back through the corresponding area of the homograft. Each of the three triangulated segments was similarly attached with approximately 7 to 10 interrupted 4-0 sutures. The homograft commissures were hitched up well at least 1 cm above the position of the excised commissural remnants of the aorta. Finally, the edges of the excised homograft sinuses were oversewn with a 4-0 continuous suture, including the margin of the intact sinus. The non-coronary sinus was retained and the underlying potential dead space was obliterated with interrupted sutures.

In case of aortic root replacement, the technique used was that described by Somerville and Ross[10].

The operative patient profile is described in table II. The sizes of the aortic homografts implanted are shown in figure 1.

Definitions of endpoints. Valve degeneration was defined according to the criteria published by Yacoub et al.[11] and includes severe regurgitation or stenosis of the aortic homograft as assessed by echocardiographic, clinical, operative, or *post-mortem* evidence and reoperations. This excludes endocarditis-related valve failure and reoperations.

Late survival represents survival from the date of hospital discharge and includes all late deaths due to

Table I. Preoperative patient profile.

No. patients	46
Females	8 (17.4%)
Age (years)	47 ± 17 (19-80)
Body surface area (m^2)	1.82 ± 0.18 (1.40-2.14)
Log EuroSCORE	6.33 ± 5.12 (1.51-29.77)
Atrial fibrillation	2 (4.3%)
NYHA class	2.13 ± 0.90 (1-4)
II	21 (45.6%)
III	10 (21.7%)
IV	3 (6.5%)
Valve lesion	
Stenosis	7 (15.2%)
Regurgitation	32 (69.6%)
Stenosis and regurgitation	7 (15.2%)
Valve pathology	
Endocarditis	12 (26.1%)
Myxomatous degeneration	11 (23.9%)
Calcific degeneration	10 (21.7%)
Aortic aneurysm or dissection	7 (15.2%)
Rheumatic	3 (6.5%)
Bicuspid	2 (4.4%)
Prosthesis degeneration	1 (2.2%)

Table II. Operative patient profile.

Subcoronary technique	21 (45.6%)
Root technique	25 (54.3%)
Urgent operation	5 (10.9%)
Reoperation	7 (15.2%)
Associated procedures	27 (58.7%)
Mitral valve replacement	3 (6.5%)
Mitral valve repair	3 (6.5%)
Coronary artery bypass grafting	4 (8.7%)
Ascendant aortic replacement	16 (34.8%)
Other	1 (2.2%)

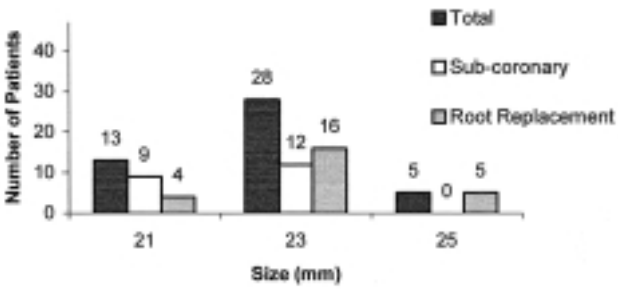

Figure 1. *Summary of homograft sizes according to the technique used for implantation.*

any cause; early mortality is excluded. Valve-related morbidity and mortality include valve degeneration plus all valve-related deaths and sudden deaths, all reoperations (including those relating to endocarditis), and all other valve-related complications[12]. Freedom from reoperation includes all reoperations on the aortic homograft.

Data collection and follow-up. All patients were periodically evaluated at our department at discharge, at 6 and 12 months, and yearly thereafter to assess the clinical status and type and frequency of postoperative complications, which were evaluated in accordance with the recently revised guidelines[12]. At each postoperative interval, transthoracic two-dimensional color Doppler echocardiographic studies were also obtained. Color Doppler echocardiography was performed with a Vingmed CFM 800 system (Vingmed Sound A/S, Oslo, Norway) equipped with a 2.5 MHz transducer. Standard M-mode and two-dimensional measurements were collected according to the criteria of the American Society of Echocardiography[13]. All Doppler measurements were obtained by averaging more than 3 cycles in patients with sinus rhythm or more than 5 cycles in those with atrial fibrillation. From the data obtained with the pulsed-wave and continuous-wave Doppler recordings, we calculated the peak and mean gradient across the prosthesis (using the long form of the modified Bernoulli equation), the effective orifice area index (EOAi), the left ventricular mass index (LVMi) using Devereux and Reichek's formula[14] and the diastolic and systolic eccentricity indexes (DEi and SEi). Homograft regurgitation was assessed during follow-up either clinically (diastolic murmur) or by means of transthoracic echocardiography with color flow.

Statistical analysis. Data are presented as mean ± SD and as percentages. The overall survival and freedom from valve-related complications and cardiac events were determined by Kaplan-Meier analysis and expressed as the percentage of patients who were event-free ± SE. The linearized rate of postoperative complications was expressed as percent per year ± SE.

All the variables listed in tables I and II were investigated for their association with hospital death, overall death, valve-related complications, sudden death, and with cardiac events at univariate analysis. The Student's t-test or Wilcoxon test was used for continuous data and the χ^2 or Fisher's test for discrete variables, as appropriate. All variables with a p value < 0.10 at univariate analysis were entered in the multivariate analysis. Predictors of hospital mortality were identified by means of a logistic regression with forward selection and with a selection cut-off set at 0.05. Predictors of events during follow-up were identified by means of Cox's proportional hazards regression with a Z-value cut-off set at 2.0. The mean values of mean gradients, EOAi, DEi, SEi and LVMi at discharge, at 6 months, and at the last follow-up (> 1 year) are also provided. Two-factor repeated measures analysis of variance (ANOVA) with the Bonferroni's multiple comparison test was used to assess the influence of time on the mean gradients, EOAi, DEi, SEi and LVMi. The alpha value for the Bonferroni test was set at 0.05. Data analysis was performed with the NCSS 2000 software (Statistical Solutions Ltd, Cork, Ireland).

Results

In-hospital outcome. The overall 30-day mortality was 4.3%, 4.1% being the in-hospital mortality for all aortic procedures performed in our department in the same period of time. Causes of in-hospital mortality were a low output syndrome in 1 patient and a major neurological event (coma) in another patient. Three patients (6.5%) required reoperation for bleeding. Atrial fibrillation was recorded in 6 patients (13.0%). New renal failure, which was censored for preoperative renal failure and defined as a rise in the serum creatinine level > 2 mg/dl postoperatively, was recorded in 2 patients (4.3%). One (2.2%) patient had a major neurological complication. A low output syndrome and an adult respiratory distress syndrome were recorded in 3 (6.5%) and in 1 (2.2%) patient respectively. In 1 patient (2.2%) minor wound infections were treated with surgical debridement and vacuum-assisted closure. The operation-to-discharge length of stay was 15 ± 8 days.

At univariate analysis, the significant determinants of in-hospital mortality were: aortic dissection ($p < 0.001$), urgent operation ($p = 0.05$) and a higher log EuroSCORE ($p = 0.05$). At multivariate analysis no independent predictors of in-hospital mortality were found.

Follow-up. The follow-up of hospital survivors (44 patients) was 100% complete at a mean follow-up of 2.8 ± 2.1 years (range 4 days to 85.8 months), for a total follow-up of 127 patient-years. There are 41 current survivors and their mean follow-up is 3.0 ± 2.2 years.

There were 3 late deaths. The causes of late death were congestive heart failure in 2 patients and sudden death in 1 patient. The linearized rate of overall death, including hospital deaths, was 3.9 ± 1.8%/year. The actuarial survival at 60 months was 91.3 ± 5.0% (Fig. 2).

One patient needed late reoperation 25 months after the initial AVR. The cause was paravalvular leakage. To date, no reoperation for structural valve degeneration has been recorded. The freedom from reoperation was 95.8 ± 4.1% (Fig. 3) and the linearized rate was 0.8 ± 0.8%/year.

Two patients needed readmission for congestive heart failure after 3.5 and 12.3 months respectively. The freedom from congestive heart failure was 94.1 ± 3.1% (Fig. 3) and the linearized rate was 1.6 ± 1.1%/year.

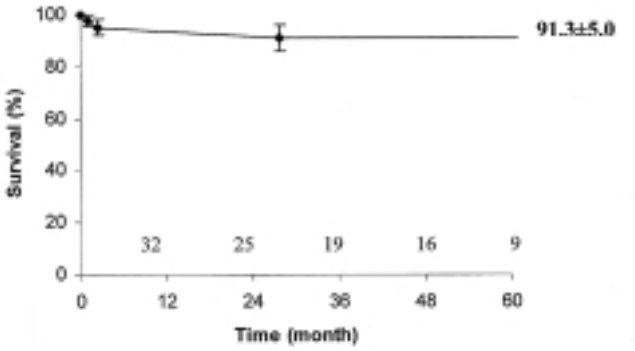

Figure 2. *Overall survival at 60 months of follow-up (early mortality has been excluded).*

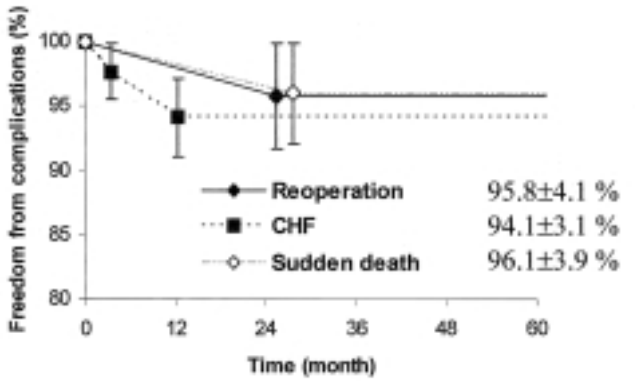

Figure 3. *Freedom from reoperation, congestive heart failure (CHF) and sudden death at 60 months of follow-up.*

Among 12 (27.3%) hospital survivors with either native or prosthetic acute valve endocarditis at the time of their homograft insertion, none had recurrent endocarditis.

At univariate analysis, the significant determinants of the overall mortality at follow-up were: aortic dissection ($p < 0.001$), prosthesis degeneration ($p = 0.004$), a higher log EuroSCORE ($p = 0.05$) and old age ($p = 0.04$). At multivariate analysis, no independent predictors of the overall mortality were found.

At univariate analysis, the significant determinants of sudden death at follow-up were: female sex ($p = 0.03$), prosthesis degeneration ($p < 0.001$) and reoperation ($p = 0.02$). At multivariate analysis no independent predictors of sudden death were found.

The significant determinants of cardiac events (congestive heart failure, angina and myocardial infarction) at univariate analysis were: old age ($p = 0.02$), a higher log EuroSCORE ($p = 0.02$) and endocarditis ($p = 0.01$). At multivariate analysis, no independent predictors of cardiac events were found.

At univariate analysis, no significant determinants of valve-related complications were found.

Hemodynamic data. In patients with severe or prevalent aortic valve stenosis, the mean ejection fraction was 49 ± 4% preoperatively, 51 ± 3% at discharge, 51 ± 7% at 6 months, and 51 ± 1% at the last follow-up (Fig. 4). At repeated measures ANOVA, a significant improvement between the preoperative vs 6-month ejection fraction ($F = 5.1$, $p = 0.04$) was recorded. The mean gradients were 56 ± 9 mmHg preoperatively, 7 ± 3 mmHg at discharge, 4 ± 3 mmHg at 6 months, and 4 ± 1 mmHg at the last follow-up (Fig. 5); EOAi was 0.74 ± 0.31 cm^2/m^2 preoperatively, 3.17 ± 0.25 cm^2/m^2 at discharge, 2.79 ± 0.46 cm^2/m^2 at 6 months, and 3.04 ± 0.23 cm^2/m^2 at the last follow-up (Fig. 6). DEi and DSi were 0.63 ± 0.02 and 0.51 ± 0.03 mm preoperatively, 0.67 ± 0.07 and 0.53 ± 0.06 mm at discharge, 0.64 ± 0.08 and 0.50 ± 0.05 mm at 6 months, and 0.63 ± 0.07 and 0.48 ± 0.05 mm at the last follow-up (Fig. 7). At repeated measures ANOVA, patients with severe or prevalent aortic valve stenosis did not show a significant variation of the investigated variables during follow-up.

In patients with severe or prevalent aortic valve insufficiency, the mean ejection fraction was 50 ± 10, 48 ± 6, 51 ± 7, and 53 ± 5% preoperatively, at discharge, at 6 months, and at the last follow-up respectively (Fig. 4). At repeated measures ANOVA, a significant im-

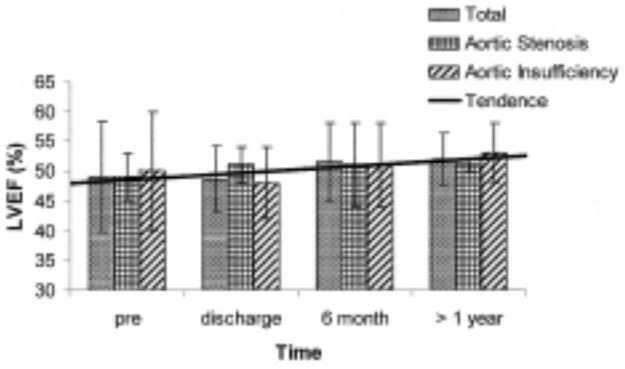

Figure 4. *Left ventricular ejection fraction (LVEF) preoperatively, at discharge, 6-month and last follow-up (1 year).*

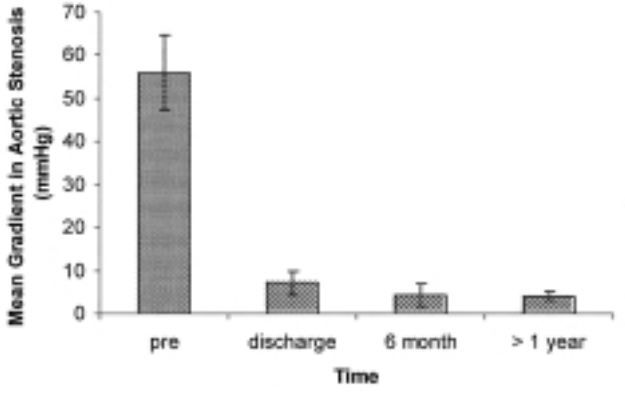

Figure 5. *Mean aortic gradient in patients with prevalent aortic valve stenosis preoperatively, at discharge, 6-month and last follow-up (1 year).*

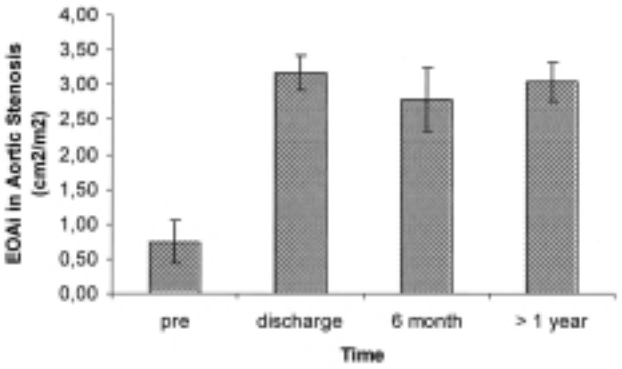

Figure 6. *Effective orifice area index (EOAi) in patients with prevalent aortic stenosis preoperatively, at discharge, 6-month and last follow-up (1 year).*

provement between the discharge vs last follow-up ejection fraction was found (F = 7.1, p = 0.01). DEi and DSi were 0.66 ± 0.08 and 0.48 ± 0.07 mm preoperatively, 0.67 ± 0.06 and 0.53 ± 0.08 mm at discharge, 0.63 ± 0.04 and 0.49 ± 0.07 mm at 6 months, and 0.63 ± 0.04 and 0.47 ± 0.04 mm at the last follow-up (Fig. 7). At repeated measures ANOVA, patients with severe or prevalent aortic valve stenosis showed a significant variation in SEi during follow-up (F = 3.4, p = 0.05) with a significant difference between the discharge vs last follow-up values (F = 6.1, p = 0.02).

Among the 44 hospital survivors, 2 patients had grade 2 (mild) aortic regurgitation during follow-up. The others had grade 0 or grade 1 (trivial) aortic regurgitation.

Regression of left ventricular hypertrophy. In patients with severe or prevalent aortic valve stenosis, LVMi decreased from 202 ± 55 g/m^2 preoperatively to 190 ± 43 g/m^2 at discharge, 141 ± 25 g/m^2 at 6 months, and 143 ± 28 g/m^2 at last follow-up (Fig. 8). By repeated measures ANOVA, a significant reduction of preoperative LVMi during follow-up (F = 7.5, p = 0.008) was recorded, with significant differences between preoperative vs discharge, 6 months, and last follow-up LVMi (p = 0.01) and discharge vs 6-month and last follow-up LVMi (p = 0.04) at the Bonferroni analysis.

In patients with severe or prevalent aortic valve insufficiency, the LVMi decreased from 177 ± 49 g/m^2 preoperatively to 165 ± 32 g/m^2 at discharge, 145 ± 31 g/m^2 at 6 months, and 138 ± 24 g/m^2 at the last follow-up (Fig. 8). At repeated measures ANOVA, a significant reduction in the preoperative LVMi was recorded during follow-up (F = 8.8, p < 0.001), with significant differences between the preoperative vs discharge, 6-month, and last follow-up LVMi (p = 0.02) and between the discharge vs 6-month and last follow-up LVMi (p = 0.03) at Bonferroni analysis.

Discussion

Homografts have been used experimentally and clinically as aortic valve substitutes for more than 30 years[7,11,15]. Many of the reasons that led to their enthusiastic embrace in the 1960s and 1970s are equally relevant today: resistance to infection, excellent hemodynamics and paucity of valve-related complications. The limitations to their universal acceptance, such as limited availability and failure due to technical error, have largely been overcome by improved methods of harvesting and preservation in homograft banks[16,17] and by improved surgical technique[3,18,19]. A major advantage of the homograft as an aortic valve substitute is the restoration of blood flow in the aortic root, sinuses, and coronary ostia to normal or near normal levels.

The normal aortic valve is a highly complex and sophisticated structure that starts opening and closing before the hemodynamic events[20]. The hemodynamic advantage translates into pressure gradients across homografts, which are usually negligible and significantly lower than the gradients across stented xenografts and modern disc valves[21,22]. As a result, the impact is a more complete regression of left ventricular hypertrophy after a successful AVR with a homograft[21]. Complete regression of hypertrophy is a main factor in keeping the left ventricle well functioning in the long term[23]. The

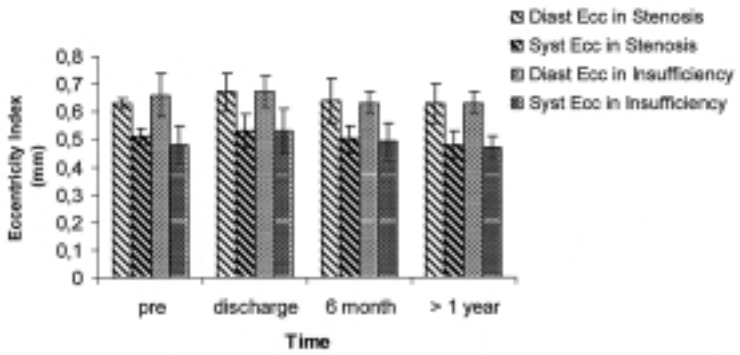

Figure 7. *Diastolic and systolic eccentricity indexes preoperatively, at discharge, 6-month and last follow-up (1 year).*

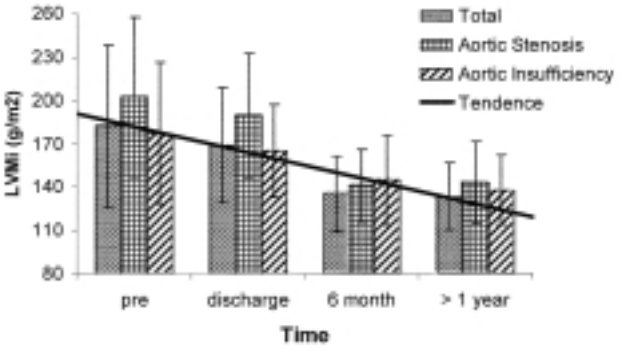

Figure 8. *Regression of left ventricular hypertrophy as indicated by left ventricular mass index (LVMi) preoperatively, at discharge, 6-month and last follow-up (1 year).*

latter may be an important determinant of long-term survival[24]. Therefore, the current interest in stentless xenografts in general and in particular for patients with a small aortic root is understandable, especially in view of the limited availability of homografts.

A first concern regarding homograft AVR is the more complex implantation technique compared with those needed for stented xenografts or mechanical valves. However, the present early mortality compares favorably with results of numerous published AVR series. Furthermore, we identified widely known risk factors for early mortality, in terms of both associated surgical procedures and patient-related factors. Notably, in our study a full root replacement with reimplantation of the coronary arteries did not entail increased risk. The fact that hospital survivors with active native or prosthetic valve endocarditis at the time of their homograft insertion were free from recurrent endocarditis indicates that homograft is resistant to infection and a 5-year freedom from infection of 100% after homograft AVR strongly supports that notion.

The main drawback of homografts and of any other biologic valves is their limited durability. It is important to emphasize that the length of follow-up may have a profound influence on the estimated freedoms from primary tissue failure. Primary tissue failure is not a trivial complication, and any measure that may reduce its incidence is strongly recommended. McGiffin[25] defined the interrelationship between overlapping mechanisms of homograft valve failure influenced by known risk factors, e.g., younger recipient age, older donor age, larger aortic root diameter, insertion technique, and valve preservation technique. All attempts should be made to reduce these risk factors as much as possible. Older homografts should be not used in younger patients, large aortic roots should be reduced to avoid the use of large homografts, and all homografts should be implanted as one functional unit. To date, we have had no evidence of structural valve degeneration but this could be due to the relatively short period of follow-up.

Echocardiographic studies have shown a lower incidence of aortic regurgitation after root replacement than after subcoronary implantation of human tissue valves[26,27]. In our series, the initial echocardiographic data and those obtained during follow-up were not suggestive of any obvious progression of the degree of incompetence. Concerns remain about the potential for late degeneration and calcification of the homograft wall, possible coronary ostial complications and the risk of reoperation, particularly in the presence of significant calcification.

During the 5-year follow-up we did not record any significant variation in the mean gradient and effective orifice area (Figs. 4 and 5) whereas, as shown in figures 7 and 8, a significant reduction in left ventricular hypertrophy and remodeling occurred in all patients. These results indicate that effective relief of left ventricular suffering was obtained regardless of the valve pathology. These results also indicate that all homografts provided an adequate hemodynamic performance in each patient and that their hemodynamic characteristics remain stable over the time.

In conclusion, although the issue of durability needs the test of a longer follow-up, replacement of the diseased aortic valve with a cryopreserved homograft offers distinct advantages in terms of excellent hemodynamics, resistance to infection and a negligible incidence of postoperative regurgitation.

References

1. Matsuki O, Okita Y, Almeida RS, et al. Two decades' experience with aortic valve replacement with pulmonary autograft. J Thorac Cardiovasc Surg 1988; 95: 705-11.
2. Daly RC, Orszulak TA, Schaff HV, McGovern E, Wallace RB. Long-term results of aortic valve replacement with nonviable homografts. Circulation 1991; 84 (Suppl): III81-III88.
3. Lund O, Chandrasekaran V, Grocott-Mason R, et al. Primary aortic valve replacement with allografts over twenty-five years. J Thorac Cardiovasc Surg 1999; 117: 77-91.
4. Niwaya K, Knott-Craig CJ, Santangelo K, et al. Advantage of autograft and homograft valve replacement for complex aortic valve endocarditis. Ann Thorac Surg 1999; 67: 1603-8.
5. Donaldson RM, Ross DN. Homograft aortic root replacement for complicated prosthetic valve endocarditis. Circulation 1984; 70 (Part 2): I178-I181.
6. Haydock D, Barratt-Boyes BG, Macedo T, Kirklin JW, Blackstone E. Aortic valve replacement for active infectious endocarditis in 108 patients. J Thorac Cardiovasc Surg 1992; 103: 130-9.
7. O'Brien MF. The 28-year, 99.3% follow-up of 1022 homograft aortic valve replacement patients. J Heart Valve Dis 2001; 10: 334-44.
8. O'Brien MF, Stafford EG, Gardner AH, Pohlner PG, McGiffin DC. A comparison of aortic valve replacement with viable cryopreserved and fresh allograft valves, with a note on chromosomal studies. J Thorac Cardiovasc Surg 1987; 94: 812-23.
9. Lang SJ, Giordano MS, Cardon-Cardo C, Summers BD,

Staiano-Coico L, Haggar DP. Biochemical and cellular characterization of cardiac valve tissue after cryo-preservation or antibiotic preservation. J Thorac Cardiovasc Surg 1994; 108: 63-7.
10. Somerville J, Ross DN. Homograft replacement of the aortic root with reimplantation of the coronary arteries. Br Heart J 1982; 47: 473-82.
11. Yacoub M, Rasmi NR, Sundt TM, et al. Fourteen-year experience with homovital homografts for aortic valve replacement. J Thorac Cardiovasc Surg 1995; 110: 186-94.
12. Edmunds LH, Clark RE, Cohn LH, Grunkemeier GL, Miller DC, Weisel RD. Guidelines for reporting morbidity and mortality after cardiac valvular operations. The American Association for Thoracic Surgery, Ad Hoc Liaison Committee for Standardizing Definitions of Prosthetic Heart Valve Morbidity. Ann Thorac Surg 1996; 62: 932-5.
13. Cheitlin MD, Alpert JS, Armstrong WF, et al. ACC/AHA guidelines for the clinical application of echocardiography: executive summary. A report of the American College of Cardiology/American Heart Association Task Force on Practice Guidelines (Committee on clinical application of echocardiography). Developed in collaboration with the American Society of Echocardiography. J Am Coll Cardiol 1997; 29: 862-79.
14. Devereux RB, Reichek N. Echocardiographic determination of left ventricular mass in man. Anatomic validation of the method. Circulation 1977; 55: 613-8.
15. Ross DN. Homograft replacement of the aortic valve. Lancet 1962; 2: 487.
16. Angell JD, Christopher BS, Hawtrey O, Angell WM. A fresh, viable human heart valve bank. Transplant Proc 1976; 8: 139-47.
17. Barratt-Boyes BG, Roche AH, Whitlock RM. Six-year review of the results of freehand aortic valve replacement using an antibiotic sterilized homograft valve. Circulation 1977; 55: 353-61.
18. Kouchoukos NT, Wareing TH, Murphy SF, Perrillo JB. Sixteen-year experience with aortic root replacement. Results of 172 operations. Ann Surg 1991; 214: 308-20.
19. O'Brien MF, McGiffin DC, Stafford EG. Allograft aortic valve implantation. Ann Thorac Surg 1989; 48: 600-9.
20. Yacoub MH, Gehle P, Chandrasekaran V, Birks EJ, Child A, Radley-Smith R. Late results of a valve-preserving operation in patients with aneurysms of the ascending aorta and root. J Thorac Cardiovasc Surg 1998; 115: 1080-90.
21. Jin XY, Zhang Z-M, Gibson DG, Yacoub MH, Pepper JR. Effects of valve substitute on changes in left ventricular function and hypertrophy after aortic valve replacement. Ann Thorac Surg 1996; 62: 683-90.
22. Lund O, Emmertsen K, Nielsen TT, et al. Impact of size mismatch and left ventricular function on performance of the St. Jude disc valve after aortic valve replacement. Ann Thorac Surg 1997; 63: 1227-34.
23. Lund O, Jensen FT. Functional status and left ventricular performance late after valve replacement for aortic stenosis: relation to preoperative data. Eur Heart J 1988; 9: 1234-43.
24. Lund O. Valve replacement for aortic stenosis: the curative potential of early operation. Scand J Thorac Cardiovasc Surg 1993; 27 (Suppl 40): 1-137.
25. McGiffin DC. Leaflet viability and the durability of the allograft aortic valve. J Thorac Cardiovasc Surg 1994; 108: 988-90.
26. Daicoff GR, Botero LM, Quintessenza JA. Allograft replacement of the aortic valve versus the miniroot and valve. Ann Thorac Surg 1993; 55: 855-9.
27. Jones EL, Shah VB, Shanewise JS, et al. Should the freehand allograft be abandoned as a reliable alternative for aortic valve replacement? Ann Thorac Surg 1995; 59: 1397-404.