Myectomy-myotomy associated with aortic valve replacement for aortic stenosis: effects on left ventricular mass regression

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Key words:
Aortic stenosis; Aortic valve replacement; Left ventricular mass.

Background. **Left ventricular outflow tract dynamic obstruction may develop after aortic valve replacement for aortic stenosis with a higher mortality and morbidity and may persist until left ventricular mass regression occurs. The aim of this study was to ascertain the effects of myectomy-myotomy on the left ventricular mass and mean wall thickness regression and on left ventricular mass normalization at least 1 year postoperatively.**

Methods. **A total of 162 patients including 71 with myectomy-myotomy (group I) and 91 without (group II) were studied at pre- and postoperative echocardiography.**

Results. **The relative left ventricular regression, after adjustment by ANCOVA analysis, was significantly greater in group I than in group II (-24.6 ± 14.7 and -16.8 ± 17.8%, p = 0.004) and the absolute mean wall thickness regression was greater in group I than in group II (-1.6 ± 1.3 vs -1.1 ± 1.6 mm, p = 0.019). Multivariable analysis showed myectomy-myotomy as an independent predictor of left ventricular mass regression.**

Conclusions. **Myectomy-myotomy may improve left ventricular mass regression after aortic valve replacement for pure aortic stenosis.**

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Introduction

Dynamic valvular and subvalvular obstructions may coexist in patients with critical aortic stenosis[1,2]. An early postoperative dynamic left ventricular (LV) outflow obstruction may develop in 10-25% of patients, with life-threatening consequences[3-5]. Concentric LV hypertrophy plays a central role in the development of postoperative dynamic obstruction[3-5], and some authors have suggested performing an extensive septal myectomy-myotomy in order to prevent it[3,6,7]. At different time intervals after aortic valve replacement (AVR), a certain degree of dynamic obstruction may develop at rest or during exercise[5,8], and may persist until LV hypertrophy has regressed. On the other hand, the persistence of the dynamic gradient could itself negatively influence the regression of the left ventricular mass (LVM). As the primary purpose of AVR surgery is to relieve the high pressure gradient and allow the regression of ventricular hypertrophy, we investigated whether myectomy-myotomy associated with AVR in patients with pure aortic stenosis may contribute to LVM regression.

Methods

Patients. Between September 1997 and December 2001, 214 consecutive patients with pure aortic stenosis underwent AVR at the Poliambulanza Hospital in Brescia, Italy; from January 2000, the patients were scheduled to undergo myectomy-myotomy. Consequently, 92 patients underwent AVR with, and 122 without myectomy-myotomy.

The patients who underwent mitral valvuloplasty (3 cases) or mitral valve replacement (6 cases) and those who had undergone previous heart surgery (5 cases) or who were echocardiographically evaluated at external referral centers (4 cases) were excluded from the analysis.

The study population therefore consisted of 196 patients, whose clinical, echocardiographic, operative and outcome data were prospectively collected in our institutional database. The patients were divided into two groups on the basis of whether they underwent myectomy-myotomy (group I) or not (group II).

Definitions. All of the clinical definitions used were those of the Society of Thoracic

Surgeons National Cardiac Surgery Database (data collection form), 1998.

Obesity was defined using the gender-specific body mass index cut-off points of 27.3 kg/m^2 for women and 27.8 kg/m^2 for men, as reported by de Simone et al.[9].

Echocardiographic measurements. In an attempt to obtain homogeneous and consistent echocardiographic data, all the preoperative and postoperative echocardiographic studies were performed by four experienced echocardiographers using an Acuson 128 or 128XP Computed Sonograph (Acuson, Mountain View, CA, USA) equipped with 2.5 to 3.5 MHz transducers. The preoperative echocardiograms were performed 0-7 days before surgery. The postoperative echocardiograms used for this study were recorded and read by echocardiographers, who were blinded to the treatment and other clinical data, at least 1 year after the operation. The pre- and postoperative LV dimensions were assessed on the basis of two-dimensionally guided M-mode tracings; the measurements were made according to the recommendations of the American Society of Echocardiography or, if the M-mode recordings were not technically adequate, on the basis of two-dimensional measurements (Appendix 1). The LVM was calculated using the American Society of Echocardiography-modified formula. In order to correct the effect of gender and overweight, LVM/height$^{2.7}$ was used as the LVM index[9].

Residual LV hypertrophy was defined as a LVM/height$^{2.7}$ > 50 g/m$^{2.7}$ for males and > 47 g/m$^{2.7}$ for females[9]. The absolute and relative LVM regressions were used to quantify the effects of AVR with or without myectomy-myotomy. The LV performance was assessed by means of the ejection fraction calculated using the Simpson's rule. Blood flow velocities in the LV outflow tract and across the valve were respectively estimated from the apical 4-chamber views by means of pulsed and continuous wave Doppler. The peak and mean valve gradients were calculated using the modified Bernoulli equation (Appendix 1). The effective orifice area was calculated using the continuity equation and indexed by body surface area.

Surgery. Surgery was performed by means of full sternotomy in 165 patients and partial sternotomy in 31. After establishing a cardiopulmonary bypass at 33°C and clamping the aorta, myocardial protection was obtained using cold blood cardioplegia delivered by the antegrade (30 patients), retrograde (133 patients) or mixed (33 patients) routes.

Myectomy-myotomy was performed after aortic valve removal. The prominent aspect of the bulging septum under the commissure between the coronary cusps is pulled using a 4/0 suture; a blade is used to make two parallel cuts with a muscle depth of about 4 mm in the long axis of the ventricle; the center piece is then cut with scissors and removed, leaving an approximately 5 mm wide rectangular area that extends for 1.5 to 2.5 cm from the valve ring towards the apex. The replacement of the aortic valve depends on the type of prosthesis.

Follow-up. The patients were clinically followed up for 3 months, and subsequently interviewed annually by telephone in order to assess their clinical status and obtain survival data. The survivors were invited to undergo an echocardiographic control at our hospital at least 1 year after surgery.

Statistical analysis. The data were statistically analyzed using SPSS 9.0 (SPSS Inc., Chicago, IL, USA). Continuous variables were expressed as mean values ± SD and 95% confidence intervals (CI), and compared using a two-tailed Student's t-test (paired or unpaired as appropriate). The percentage of LVM/height$^{2.7}$ regression was adjusted by ANCOVA for the covariates that correlated with mass regression in the univariate analysis and were statistically different between the groups, i.e. the preoperative LVM/height$^{2.7}$ ($r = 0.38$, $r^2 = 14\%$, $p = 0.0001$) and prosthetic gradient ($r = 0.17$, $r^2 = 0.3\%$, $p = 0.03$). In order to determine which of 14 continuous or categorical variables (Appendix 2) were independently associated with the percentage regression of the LVM/height$^{2.7}$, a stepwise multiple regression analysis was made, with a p value < 0.1 being considered as statistically significant. The variables identified in the first analysis were reinserted in the multiple regression model using the block procedure. The cumulative survival was assessed with Kaplan-Meier's product limit method and the comparison between groups made with a log-rank test.

Results

The clinical characteristics of the 196 patients (85 in group I and 111 in group II) are shown in table I, and the preoperative echocardiographic data in table II. In no case was a subaortic LV outflow tract velocity > 2 m/s found preoperatively. The two groups were homogeneous in terms of demographic, clinical and echocardiographic parameters excluding LVM/height$^{2.7}$ (72.5 ± 14.3 g in group I vs 78.6 ± 19.8 g in group II, $p = 0.025$). Concomitant coronary artery bypass graft was performed in 45.8% of patients in group I (39/85) and in 33.3% in group II (37/111) ($p = 0.101$); the ascending aorta was replaced in 3.5% (3/85) of patients in group I and in 4.5% (5/111) in group II ($p = 0.981$). Mechanical prostheses were implanted in 54 patients (17 in group I and 37 in group II), stented bioprostheses in 121 (53 in group I and 68 in group II), and stentless prostheses in 21 (13 in group I and 8 in group II). There were no differences between the two groups in terms of the proportion of prosthesis type and size, and no difference in the inner diameter/body surface area of the

Table I. Clinical characteristics.

Parameters	Group I	Group II	p
No. patients	85	111	
Age (years)	72.9 ± 9.6 (CI 58.1÷85.7)	70.7 ± 9.4 (CI 54.4÷83.7)	0.151
Males	52.9%	53.1%	0.908
Hypertension	64.7%	65.9%	0.502
Diabetes	13.2%	21.9%	0.113
Renal insufficiency	1.5%	3.3%	0.426
Arteriopathy	16.1%	23.1%	0.192
BSA (m^2)	1.81 ± 0.2 (CI 1.46÷2.11)	1.79 ± 0.2 (CI 1.46÷2.19)	0.419
BMI (kg/m^2)	26.1 ± 3.7 (CI 20.4÷31.9)	26.2 ± 4.8 (CI 19.7÷37.8)	0.806
Obesity	35.2%	31.5%	0.481
Coronary artery disease	48.8%	33.3%	0.101
NYHA functional class	2.4 ± 0.6	2.3 ± 0.7	0.326
Elective	90.5%	94.5%	0.424
Urgent/emergency	9.5%	5.4%	0.554
Prosthesis internal diameter/BSA (mm/m^2)	10.8 ± 1.2 (CI 9÷13.2)	10.7 ± 1.3 (CI 8.3÷12.7)	0.230
Mechanical prosthesis (mm)			
19	0	2	NS
21	2	13	NS
23	14	18	NS
25	1	4	NS
Stented bioprosthesis (mm)			
19	12	34	NS
21	22	23	NS
23	17	10	NS
25	2	1	NS
Stentless valve (mm)			
21	8	2	NS
23	4	6	NS
25	1	0	NS
ECC time (min)	115 ± 25 (CI 83÷165)	114 ± 35 (CI 68÷178)	0.859
ACC time (min)	80 ± 21 (CI 53÷123)	74 ± 22 (CI 45÷118)	0.06

ACC = aortic cross-clamping; BMI = body mass index; BSA = body surface area; CI = confidence interval; ECC = extracorporeal circulation.

Table II. Preoperative echocardiographic data.

	Group I (n=71)	Group II (n=91)	p
Aortic area indexed (cm^2/m^2)	0.45 ± 0.08 (CI 0.29÷0.58)	0.47 ± 0.07 (CI 0.35÷0.59)	0.105
Aortic gradient (mmHg)	50 ± 13 (CI 30.9÷74.5)	49 ± 13 (CI 26.1÷71.5)	0.629
Ejection fraction (%)	58 ± 11 (CI 34÷76)	58 ± 12 (CI 34÷74)	0.967
LVDD (mm)	50.3 ± 5.9 (CI 39.8÷60.2)	52.1 ± 7.8 (CI 40.3÷66.4)	0.085
IVS (mm)	13.8 ± 1.7 (CI 11.9÷17)	13.5 ± 1.6 (CI 10.9÷17.1)	0.373
PW (mm)	12.9 ± 1.5 (CI 10.8÷15.5)	12.9 ± 1.4 (CI 10.9÷15.6)	0.812
Mean LV thickness (mm)	13.4 ± 1.4 (CI 11.7÷15.6)	13.3 ± 1.4 (CI 11.1÷15.4)	0.562
RLVWT	0.54 ± 0.1 (CI 0.40÷0.72)	0.52 ± 0.1 (CI 0.36÷0.67)	0.230
LVM/$hight^{2.7}$ (g)	72.5 ± 14.3 (CI 52.2÷98.9)	78.6 ± 19.8 (CI 52.2÷122)	0.025

IVS = interventricular septum; LV = left ventricular; LVDD = left ventricular diastolic diameter; LVM = left ventricular mass; PW = posterior wall; RLVWT = relative left ventricular wall thickness.

prostheses (10.8 ± 1.2 mm in group I and 10.7 ± 1.3 mm in group II, p = 0.230).

Two patients died of heart failure in hospital (one in each group). There were no complications related to the myectomy-myotomy.

The length of 100% complete follow-up was 1.5 ± 0.5 years in group I and 3 ± 1.1 years in group II (p < 0.0001). Late deaths were observed in 2 patients in group I (one cardiac and one non-cardiac) and in 8 in group II (five cardiac and three for non-cardiac). The actuarial survival at 2.9 years was 98.8% (CI 96.4-100%) in group I (Fig. 1), and 96.3% (CI 88.3-99.3%) in group II (Fig. 2) without any statistical between-group difference (log-rank test p = 0.806).

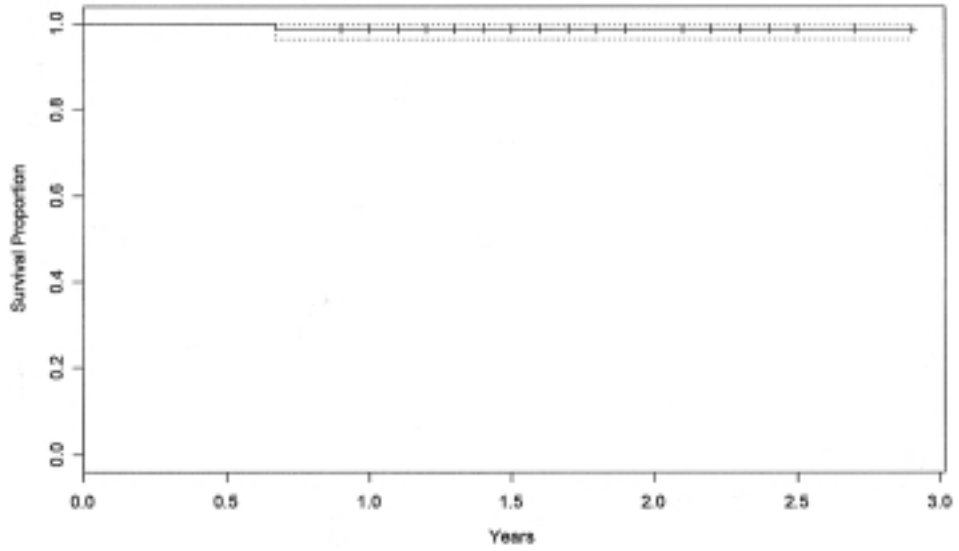

Figure 1. *Actuarial survival (*dotted lines *95% confidence interval) of the patients discharged after aortic valve replacement with myectomy-myotomy.*

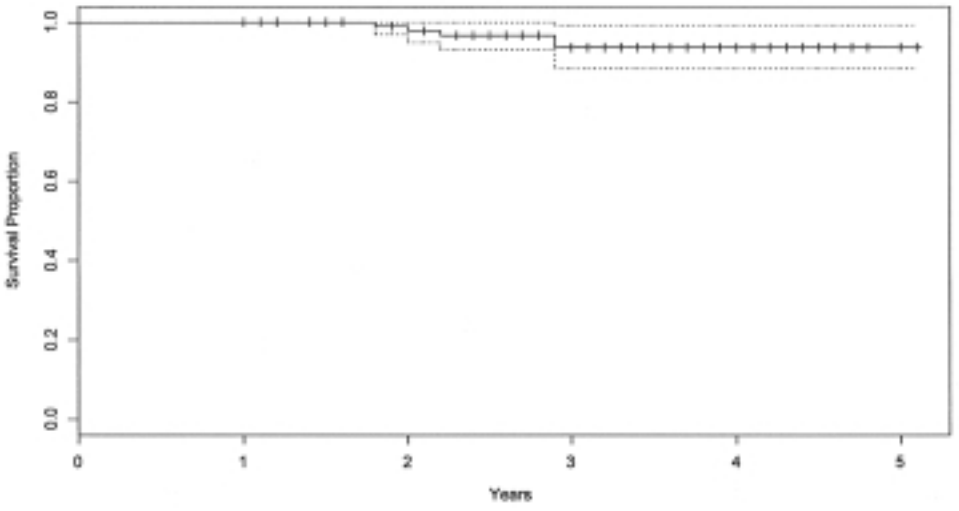

Figure 2. *Actuarial survival (*dotted lines *95% confidence interval) of the patients discharged after aortic valve replacement without myectomy-myotomy.*

Follow-up echocardiographic study. Data were available for 162 of the 184 surviving patients invited to undergo an echocardiographic control after at least 1 year (71 in group I and 91 in group II) (Table III).

Hemodynamic measurements. No structural or functional prosthesis abnormality was found in either group. The average mean transprosthetic gradient was significantly smaller in group I (15.5 ± 6.3 vs 17.8 ± 6.8 mmHg, p = 0.034). The indexed effective orifice area was 0.85 ± 0.18 cm^2/m^2 in group I and 0.83 ± 0.27 cm^2/m^2 in group II, with no statistically significant difference between them (p = 0.659).

Left ventricular mass and morphology. The LV dimensions, interventricular septum, posterior wall and relative LV wall thickness decreased significantly in both groups, without any statistically significant between-group differences.

The LVM/$height^{2.7}$ ratio also decreased significantly in both groups (p = 0.0001), but was significantly lower in group I (55.7 ± 12.8 vs 62.8 ± 15.4 g, p = 0.002).

The relative LVM regression was greater in group I (-22.3 ± 14.8 vs -18.1 ± 17.6%), but the difference was not statistically significant (p = 0.112). After adjustment by ANCOVA, the difference between the groups reached statistical significance (p = 0.004), with the regression being greater in myectomy-myotomy patients (-24.6 ± 14.7 vs -16.8 ± 17.8%). Furthermore, multiple regression analysis showed that myectomy-myotomy was an independent predictor of LVM regression (Table IV), with β = -0.306 and p = 0.001 in a model with r = 0.48, r^2 = 0.23, and p < 0.0001.

Table III. Postoperative echocardiographic data.

	Group I (n=71)	Group II (n=91)	p
IEOA (cm^2/m^2)	0.85 ± 0.18 (CI 0.6÷1.3)	0.83 ± 0.27 (CI 0.49÷1.3)	0.659
Aortic gradient (mmHg)	15.5 ± 6.3 (CI 6.3÷27.3)	17.8 ± 6.8 (CI 8.7÷29.5)	0.034
Ejection fraction (%)	65 ± 10* (CI 45÷79)	63 ± 10** (CI 46÷76)	0.407
LVDD (mm)	47.8 ± 4.9* (CI 39.2÷57.2)	49 ± 6* (CI 38.8÷59.2)	0.165
LVDD regression (mm)	-2.4 ± 5.8 (CI -13.6÷6.4)	-3.1 ± 6.4 (CI -15.9÷7.1)	0.503
IVS (mm)	12.3 ± 1.6* (CI 9.8÷14.6)	12.7 ± 1.7* (CI 10.1÷15.7)	0.154
PW (mm)	11.1 ± 1.6* (CI 8.3÷14.1)	11.6 ± 1.7* (CI 8.6÷14.4)	0.081
RLVWT	0.47 ± 0.07* (CI 0.36÷0.59)	0.47 ± 0.09** (CI 0.33÷0.64)	0.931
RLVWT regression (%)	-10.3 ± 22.3 (CI -15.5÷-4.9)	-6.1 ± 27.5 (CI -11.8÷-0.4)	0.305
Mean LV thickness (mm)	11.7 ± 1.4* (CI 9.1÷14.1)	12.1 ± 1.5* (CI 10÷14.7)	0.069
Mean LV thickness regression	-1.6 ± 1.3 (CI -4.3÷0.14)	-1.1 ± 1.6 (CI -3.4÷1.04)	0.019
LVM/height$^{2.7}$ (g)	55.7 ± 12.8 (CI 38.8÷81.9)	62.8 ± 15.4 (CI 41.9÷95.7)	0.002
LVM/height$^{2.7}$ regression (%)	-22.3 ± 14.8 (CI -45.2÷2.9)	-18.1 ± 17.6 (CI -43.6÷19.3)	0.112
Residual hypertrophy	63.4% (45/71)	86.8% (79/91)	0.0001

IEOA = indexed effective orifice area; IVS = interventricular septum; LV = left ventricular; LVDD = left ventricular diastolic diameter; LVM = left ventricular mass; PW = posterior wall; RLVWT = relative left ventricular wall thickness. * $p < 0.0001$, ** $p < 0.01$ postoperative vs preoperative.

Table IV. Multiple linear regression analysis.

Variables	LVM/hight$^{2.7}$ % regression (model r = 0.48, $r^2 = 0.23$, $p < 0.0001$)	
	β	p
Body mass index	0.145	0.044
Preoperative LVM/height$^{2.7}$	-0.434	< 0.0001
Myectomy-myotomy	-0.306	0.001

LVM = left ventricular mass.

The absolute decrease in LV mean wall thickness was significantly greater in group I (-1.6 ± 1.3 vs -1.1 ± 1.6 mm, $p = 0.019$).

Discussion

The aim of AVR in aortic valve disease is to relieve the symptoms secondary to abnormal hemodynamics and to normalize LVM, which is an important factor in decreasing cardiovascular morbidity and mortality rates. It is presumed that correction of the lesion removes the hypertrophic stimulus and thus allows favorable LV remodeling to occur. Different patient series have shown that a number of variables are statistically significant factors in decreasing LVM: patient-prosthesis mismatch[10], and the size[11] and type of the prosthesis[12]. However, some results are conflicting mainly because of a lack of homogeneous definitions, different study populations including patients with aortic insufficiency or mixed valvular lesions, and different time intervals between echocardiographic measurements.

Over the last 10 years, various replacement valves have been introduced. Stentless valves have led to encouraging but still controversial results: Walther et al.[12] reported that the LVM regression obtained with stentless valves was greater than that obtained with stented valves, whereas De Paulis et al.[13] failed to confirm this finding. Furthermore, it is well known that LVM regression is not only a prosthesis-related phenomenon as other factors, such as gender, the type of aortic valve lesion, hypertension, cardiac rhythm and ejection fraction, can affect postoperative LV remodeling[14,15].

Concentric hypertrophy is the characteristic structural pattern of LV hypertrophy in pure aortic stenosis, and plays a crucial role in the development of the postoperative dynamic gradient. This may occur at the mid-cavity level, in the LV outflow tract caused by a systolic anterior motion of the mitral valve[5] or by subaortic hypertrophy[16]. Bartunek et al.[5] found, as a result of different mechanisms, a mean relative LV wall thickness of 0.53 ± 0.14 mm in patients who developed a postoperative dynamic gradient at rest or during instrumental stress. Furthermore, in a series of 11 patients with pure severe aortic stenosis and without any anatomic signs of subvalvular obstruction, Bird et al.[1] found a large subvalvular gradient that seemed to worsen after AVR.

In order to avoid the hemodynamic complications of early postoperative dynamic gradients, various therapeutic approaches have been adopted, the most effective of which are considered to be the avoidance of inotropic agents and hypovolemia, and the use of calcium-channel blockers or β-blockers.

Some authors[6] routinely perform myectomy-myotomy in AVR for aortic stenosis with concentric LV hypertrophy in order to reduce the morbidity and mortality related to postoperative dynamic obstruction, but this approach has been questioned and criticized[5].

Myectomy-myotomy is currently recommended in a limited subgroup of surgical patients with pure aortic stenosis, an interventricular septum > 18 mm and asymmetrical hypertrophy[17,18].

In all patients with concentric LV hypertrophy, and even in the absence of a gradient at rest, some degree of gradient may develop under stress after AVR for aortic stenosis or in cases of hypertension[5,8,16], and may affect the speed of LVM regression until LVM normalization. In support of this hypothesis, Zussa et al.[8] found a LV outflow tract gradient during exercise or dobutamine testing during the months following AVR for aortic stenosis.

During effort, the interventricular septum base protrusion into the LV outflow tract may be a cause of obstruction. In a group of elderly patients with effort dyspnea and a normal LV systolic function, Henein et al.[16] found that subaortic hypertrophy was a cause of outflow obstruction. Furthermore, one of the characteristics of elderly patients is the increased angularity of the aorta in relation to the long axis of the ventricle, and it has been suggested that, together with some shrinkage of the heart, this morphology leads to upper septal bulging and a narrowed outflow tract sufficient to cause obstruction at rest or during effort[16]. Shapiro et al.[19] found severe septal bulging in at least 10% of their patients with aortic stenosis of any degree, with or without associated hypertension.

With the aim of obtaining a positive early and late effect, we performed AVR with myectomy-myotomy in a consecutive series of pure aortic stenosis patients considered to be at risk of developing a postoperative dynamic gradient. Their mean relative LV wall thickness was 0.53 ± 0.1 mm, their mean age 72 ± 9 years, and 65% had associated hypertension.

In an attempt to verify our hypothesis, we analyzed late LV remodeling in two homogeneous groups treated with and without myectomy-myotomy. The two groups proved to have a similar LV diameter reduction and ejection fraction improvement, but myectomy-myotomy seemed to be significantly effective in reducing concentric hypertrophy. After myectomy-myotomy, the LV outflow tract may enlarge and this could reduce the gradient developing at rest or during effort and probably lead to better LV remodeling.

The regression was due more to the LV wall regression than the LV dimensions because the mean wall thickness decreased more in group I than in group II (-1.6 ± 1.3 vs -1.1 ± 1.6 mm, p = 0.019), whereas there was no difference in the LV diameter (-2.4 ± 5.8 mm in group I and -3.1 ± 6.4 mm in group II, p = 0.503). Our results show that this mechanism is responsible for the possibly late effects of LVM regression.

With ANCOVA adjustment, the percentage of LVM regression was significantly greater in group I than in group II, and multiple linear regression analysis showed that myectomy-myotomy was a powerful predictor of LVM regression. The other variable (baseline LVM) identified in our analysis as a powerful predictor of LVM regression has previously been explained by other authors[10]. The model obtained using multiple linear regression analysis explained almost a quarter of the variance (9% accounted for by myectomy-myotomy), whereas three quarters remained unexplained. However, it is well known that LVM regression is a highly complex phenomenon[20] that is influenced by hemodynamic and non-hemodynamic factors, such as genetic and environmental factors[21].

Study limitations. In addition to its retrospective nature, the limitations of the study include:
• the mean age of the population as a whole was 71.9 years, and so the inferences derived from our results may apply only to elderly patients;
• the possible significant variability induced by four different echocardiographers should be evaluated by an independent core-lab examination[22];
• the analysis was made using the data obtained from 88% of the survivors;
• the incompleteness of the data concerning the duration and type of different antihypertensive drugs reduces the precision of the analysis because of their effect on LVM regression.

Clinical implications. Our study shows that myectomy-myotomy could influence LVM regression after AVR in patients with aortic stenosis. This attractive hypothesis must be validated by prospective randomized studies. Unlike some other authors[23,24], we did not observe any complications such as interventricular septum perforation, or partial or complete atrioventricular block and thus in our opinion myectomy-myotomy may be considered a safe procedure.

Appendix 1. Echocardiographic data.

Structural left ventricular measurements
Left ventricular variables were measured using the M-mode tracings: end-diastolic diameter (EDD) and end-systolic diameter, posterior wall thickness (PWT) and interventricular septum (IVS) thickness.
The relative left ventricular wall thickness (RLVWT) was calculated as EDD/(PW+PW).
The left ventricular mass (LVM) in grams was calculated using the American Society of Echocardiography (ASE)-modified formula:

$$LVM_{ASE} = 0.8\ [1.04\ (IVS_d + LVID_d + PWT_d)^3 - LVID^3] - 13.6\ g$$

Absolute LVM regression = postoperative LVM – preoperative LVM, expressed in grams.
Relative LVM regression (%) = (preoperative LVM – postoperative LVM)/preoperative LVM

Doppler measurements
Modified Bernoulli equation for the mean and peak pressure drops:

$$\Delta p = 4^* (V^2_1 - V^2_2).$$

V_1 = velocity calculated using continuous Doppler across the prosthetic aortic valve, V_2 = velocity calculated using pulsed

Doppler in the left ventricular outflow tract.
The prosthetic effective orifice area (EOA) was calculated using the modified continuity equation:

$$EOA = 3.14*2D/4*VTI_{LVOT}/VTI_{AV}.$$

Appendix 2. Variables tested in the multiple linear regression analysis and found to be non-significant.

Age (continuous)
Sex (0 = female; 1 = male)
History of hypertension (0 = no; 1 = yes)
Chronic renal insufficiency (0 = no; 1 = yes)
Diabetes (0 = no; 1 = yes)
Arteriopathy (0 = no; 1 = yes)
Sinus rhythm (0 = no; 1 = yes)
Coronary artery disease (0 = no; 1 = yes)
Preoperative ejection fraction (continuous)
Indexed effective orifice area (continuous)
Follow-up time (continuous)
Body mass index (continuous)
Myectomy-myotomy (0 = no; 1 = yes)
Left ventricular mass/height$^{2.7}$ (continuous)

References

1. Bird JJ, Murgo JP, Pasipoularides A. Fluid dynamics of aortic stenosis: subvalvular gradient without subvalvular obstruction. Circulation 1982; 66: 835-40.
2. Bloom KR, Meyer RA, Bove KE, Kaplan S. The association of fixed and dynamic left ventricular outflow obstruction. Am Heart J 1975; 89: 586-90.
3. Aurigemma G, Battista S, Orsinelli D, Sweeney A, Pape L, Cuenoud H. Abnormal left ventricular intracavitary flow acceleration in patients undergoing aortic valve replacement for aortic stenosis. A marker for high postoperative morbidity and mortality. Circulation 1992; 86: 926-36.
4. Orsinelli DA, Aurigemma GP, Battista S, Krendel S, Gaash WH. Left ventricular hypertrophy and mortality after aortic valve replacement for aortic stenosis. J Am Coll Cardiol 1993; 22: 1679-83.
5. Bartunek J, Sys SU, Rodrigues AC, Schuerbeeck EV, Mortier L, de Bruyne B. Abnormal systolic intraventricular flow velocities after valve replacement for aortic stenosis. Mechanisms and prognostic significance. Circulation 1996; 93: 712-9.
6. Brazao AJ, Prieto D, de Oliveira JF, Eugenio L, Antunes MJ. Aortic valve replacement with small-sized disc prostheses (Medtronic Hall). J Heart Valve Dis 1999; 8: 680-6.
7. Laurent M, Leborgne O, Clement C, et al. Systolic intracavitary gradients following aortic valve replacement: an echo-Doppler study. Eur Heart J 1991; 12: 1098-106.
8. Zussa C, Polesel E, Rigo F, Guarraciono F. Left ventricular remodeling after aortic valve replacement with the Toronto-SPV prosthesis. Semin Thorac Cardiovasc Surg 1999; 11 (Suppl 1): 103-6.
9. de Simone G, Daniels SR, Devereux RB, et al. Left ventricular mass and body size in normotensive children and adults: assessment of allometric relations and impact of overweight. J Am Coll Cardiol 1992; 20: 1251-60.
10. Del Rizzo D, Abdoh A, Cartier P, Doty D, Westaby S. Factors affecting left ventricular mass regression after aortic valve replacement. Semin Thorac Cardiovasc Surg 1999; 11 (Suppl 1): 114-20.
11. Barner HB, Labovitz AJ, Fiore AC. Prosthetic valves for the small aortic root. J Card Surg 1994; 9 (Suppl): S154-S157.
12. Walther T, Falk V, Langebartels G, et al. Regression of left ventricular hypertrophy after stentless versus conventional aortic valve replacement. Semin Thorac Cardiovasc Surg 1999; 11 (Suppl): 18-21.
13. De Paulis R, Sommariva L, Colagrande L, et al. Regression of left ventricular hypertrophy after aortic valve replacement for aortic stenosis with different valve substitutes. J Thorac Cardiovasc Surg 1998; 116: 590-8.
14. Jin XY, Pillai R, Westaby S. Medium-term determinants of left ventricular mass index after stentless aortic valve replacement. Ann Thorac Surg 1999; 67: 411-6.
15. Lamb HJ, Beyerbacht HP, de Roos A, et al. Left ventricular remodeling early after aortic valve replacement: differential effects on diastolic function in aortic valve stenosis and aortic regurgitation. J Am Coll Cardiol 2002; 40: 2182-8.
16. Henein MY, O'Sullivan C, Sutton GC, Gipson DG, Coats AJ. Stress-induced left ventricular outflow tract obstruction: a potential cause of dyspnea in the elderly. J Am Coll Cardiol 1997; 30: 1301-7.
17. Panza JA, Maron BJ. Valvular aortic stenosis and asymmetric septal hypertrophy: diagnostic considerations and clinical and therapeutic implications. Eur Heart J 1988; 9 (Suppl E): 71-6.
18. Hess OM, Schneider J, Turina M, Carrol JD, Rothlin M, Krayenbuehl HP. Asymmetric septal hypertrophy in patients with aortic stenosis: an adaptative mechanism or a coexistence of hypertrophic cardiomyopathy? J Am Coll Cardiol 1983; 1: 783-9.
19. Shapiro LM, Howat AP, Crean PA, Westgate CJ. An echocardiographic study of localized subaortic hypertrophy. Eur Heart J 1986; 7: 127-32.
20. Friddle CJ, Koga T, Rubin EM, Bristow J. Expression profiling reveals distinct sets of genes altered during induction and regression of cardiac hypertrophy. Proc Natl Acad Sci USA 2000; 97: 6745-50.
21. de Simone G, Pasanisi F, Contaldo F. Link of nonhemodynamic factors to hemodynamic determinants of left ventricular hypertrophy. Hypertension 2001; 38: 13-8.
22. Gosse P, Dubourg O, Gueret P. Regression of left ventricular hypertrophy with echocardiography: some lessons from the LIVE study. J Hypertens 2003; 21: 217-21.
23. Maron BJ, Bonow RO, Cannon RO, Leon MB, Epstein SE. Hypertrophic cardiomyopathy. Interrelations of clinical manifestations, pathophysiology, and therapy. N Engl J Med 1987; 316: 780-9, 844-52.
24. Maron BJ, Epstein SE, Morrow AG. Symptomatic status and prognosis of patients after operation for hypertrophic obstructive cardiomyopathy: efficacy of ventricular septal myotomy and myectomy. Eur Heart J 1983; 4 (Suppl F): 175-85.