Anatomic Atrial Remodeling After Mitral Valve Surgery in Permanent Atrial Fibrillation

Fernando Hornero Sos,[a] José A. Montero Argudo,[a] Sergio Canovas López,[a] Óscar Gil Alabarova,[a] Rafael García Fuster,[a] José Leandro Pérez Bosca,[b] Felipe Atienza Fernández,[b] Rafael Payá Serrano,[b] María José Dalmau Sorli,[a] María Bueno Codoñer,[a] and José Buendía Miñano[a]

[a]Servicio de Cirugía Cardíaca, Hospital General Universitario, Valencia.
[b]Servicio de Cardiología, Hospital General Universitario, Valencia. Spain.

Background. Mitral valve pathology is frequently associated with atrial dilation and fibrillation. Mitral surgery allows immediate surgical atrial remodeling, and in those cases in which sinus rhythm is achieved, it is followed by late remodeling. The aim of this study was to investigate the process of postoperative atrial remodeling in patients with permanent atrial fibrillation who undergo mitral surgery.

Patients and method. In a prospective randomized trial, 50 patients with permanent atrial fibrillation and dilated left atrium, repaired surgically, were divided into two groups: group I, 25 patients with left atrial reduction and mitral surgery, and group II, 25 patients with isolated valve surgery. The characteristics of both groups were considered homogeneous in the preoperative assessment.

Results. After a mean follow-up of 31 months, 46% of the patients in group I versus 18% in group II regained sinus rhythm ($p = 0.06$). Atrial remodeling with shrinkage occurred in patients who recovered sinus rhythm, with larger changes in group II (–10.8% left atrial volume reduction in group I compared to –21.5% in group II; $p < 0.05$). The atrium became enlarged again in patients whose atrial fibrillation did not remit (+16.8% left atrial volume increase in group I versus +8.4% in group II; $p < 0.05$).

Conclusions. Mitral surgery produces a postoperative decrease in atrial volume, especially when reduction techniques are used. Late left atrial remodeling was influenced by the type of atrial rhythm and postoperative surgical volume.

Key words: *Remodeling. Atrium. Surgery. Atrial fibrillation.*

Full English text available at: www.revespcardiol.org

Remodelado anatómico auricular tras la cirugía de la valvulopatía mitral con fibrilación auricular permanente

Introducción y objetivos. La valvulopatía mitral se asocia con frecuencia a dilatación y fibrilación auriculares. La cirugía mitral permite un remodelado auricular quirúrgico inmediato que, además, en aquellos casos en los que se consigue restablecer el ritmo sinusal, se sigue de un remodelado tardío. El objetivo de este estudio es conocer el proceso de remodelado auricular postoperatorio en pacientes intervenidos de valvulopatía mitral en fibrilación auricular permanente.

Pacientes y método. De forma prospectiva, 50 pacientes en fibrilación auricular permanente por valvulopatía mitral con indicación de reparación quirúrgica, fueron aleatorizados en 2 grupos: 25 pacientes con reducción de la aurícula izquierda y cirugía mitral (grupo I), y 25 pacientes con solo cirugía mitral (grupo II). Preoperatoriamente ambos grupos fueron homogéneos.

Resultados. Tras un seguimiento medio de 31 meses, el 46% de los pacientes del grupo I recuperó el ritmo sinusal, frente al 18% del grupo II ($p = 0,06$). En todos los pacientes que recuperaron el ritmo sinusal se produjo un remodelado auricular con regresión del tamaño, que fue más acentuado en el grupo II (–10,8% de reducción del volumen auricular izquierdo en el grupo I frente a –21,5% en el grupo II; $p < 0,05$). Los pacientes que permanecieron en fibrilación auricular presentaron una nueva dilatación auricular, en especial los del grupo I (+16,8% de volumen auricular izquierdo en el grupo I frente a +8,4% en el grupo II; $p < 0,05$).

Conclusiones. La cirugía mitral produce una disminución quirúrgica del volumen auricular postoperatorio, en especial cuando se asocian técnicas de reducción. El remodelado auricular tardío de la aurícula izquierda dependió del tipo de ritmo auricular y del volumen auricular quirúrgico postoperatorio.

Palabras clave: *Remodelado. Aurícula. Cirugía. Fibrilación auricular.*

INTRODUCTION

The atria of the heart are anatomically dynamic structures that can adapt in response to various pathophysiologic mechanisms. One of these is intrinsic atrial fibrillation (AF), which can produce both

Correspondencia: F. Hornero Sos.
Servicio de Cirugía Cardíaca. Hospital General Universitario de Valencia.
Avda. Tres Cruces, s/n. 46014 Valencia. España.
E-mail: hornero_fer@gva.es

Received 13 December 2002.
Accepted for publication 28 March 2003.

ABBREVATIONS

AF: atrial fibrillation.
AI: left atrium.
AD: right atrium.

electrophysiologic and morphologic changes in atria. Over time, AF causes tissue remodeling, which begins with metabolic alterations. Thereafter, cellular and anatomical changes occur. This adaptive process is termed atrial remodeling. There are different degrees of atrial remodeling, which correspond to distinct stages in the process of atrial tissue modification.[1-6]

Very few studies of the atrial remodeling that occurs after cardiac surgery have been performed.[7] The objective of the present study was to evaluate prospectively the morphological effects of surgery in a group of patients in permanent AF who had mitral lesions that required surgery. We carried out an echocardiographic study in these patients to compare the atrial remodeling that occurred after mitral valve surgery alone with that occurring when surgical reduction of the atrium was also performed.

PATIENTS AND METHODS

We studied the process of atrial remodeling prospectively in a group of patients in permanent AF who underwent operations for mitral valve disease. The study included 50 patients who were randomized into two groups: group I comprised 25 patients who underwent surgical reduction of the left atrium (LA) during mitral surgery, and group II comprised 25 patients who underwent mitral surgery alone. All patients were informed about the surgical procedures and the study and written consent was obtained. The study was approved by the Institutional Clinical Trails Committee and it formed part of ongoing investigational study, FIS 99/0484, whose preliminary results have been previously reported in this journal.[8]

Inclusion criteria for the study were mitral disease requiring surgery and permanent AF that had been electrocardiographically documented for more than 3 months. Exclusion criteria were age less than 18 years, pregnancy, paroxysmal AF or permanent AF of less than 3 months' duration, use of a permanent pacemaker, radiological evidence of atrial calcification, significant aortic or tricuspid disease requiring surgery, the presence of any condition that could cause atrial dilatation because of ventricular diastolic dysfunction (e.g., systemic arterial hypertension, reduced ejection fraction, ischemic heart disease, or ventricular hypertrophy), a need for other surgical procedures, or participation in another trial protocol. The patients' preoperative clinical characteristics and details of the surgical procedures performed are listed in Table 1. There were no statistically significant differences between the two groups. Before the operation, the majority of patients presented with dyspnea on exertion and loss of functional capacity over the previous few years. In addition, 20 patients (80%) in group I and 18 (72%) in group II were in New York Heart Association (NYHA) functional class III or IV before the operation. Four patients in group I and two in group II had experienced previous thromboembolic events.

Mitral surgery was carried out using standard surgical techniques. Extracorporeal circulation was instituted using an arterial cannula in the ascending aorta and two venous cannulas in the vena cava. After extracorporeal circulation was started, the mitral valve was approached via the interatrial sulcus. After the mitral valve had been repaired in group I patients, the LA was surgically reduced by partially removing the posterior atrial wall using a previously described technique.[8] Once atrial

TABLE 1. **Preoperative clinical characteristics of patients in groups I and II and details of the surgery performed**

	Group I	Group II
Age, years	59.4±11.7	60.7±10.9
Sex, male/female	4/21	7/18
Mitral disease		
Stenosis, n (%)	9 (36%)	7 (28%)
Regurgitation, n (%)	6 (24%)	8 (32%)
Both lesions, n (%)	10 (40%)	10 (40%)
Mitral disease		
Rheumatic, n (%)	19 (76%)	19 (76%)
Degenerative, n (%)	6 (24%)	6 (24%)
Duration of AF, years	6±5.7	6.1±5.8
< 1 year, n	4	2
1 to 3 years, n	6	6
3 to 6 years, n	4	5
>6 years, n	11	12
F-wave, mV	0.076±0.062	0.082±0.069
Previously administered antiarrhythmics, n	2.2±0.6	2.3±0.6
Duration of anticoagulation therapy, years	5.3±4.5	6.4±5.5
Mitral prosthesis		
Biological, n	3	2
Mechanical, n	14	19
Mitral commissurotomy, n	5	3
Mitral valvuloplasty, n	3	1
Duration of extracorporeal circulation, min	104±29	89±29
Duration of myocardial ischemia, min	71±21	64±25
Hospital stay, days	9.4±3.2	9.0±3.4
Hospital mortality	0	0

All values are expressed as means±standard deviations. The figures shown between parentheses are percentages. AF indicates atrial fibrillation.

surgery had been completed, the surgical wound in the atrium was closed using a continuous polypropylene 3/0 double suture and the surgical procedure was finished.

Preoperative and postoperative echocardiography was carried out by one of three randomly selected investigators using a Hewlett-Packard Sonos 1500 Doppler scanner. These investigators were blinded to the results of previous evaluations. In addition to the echocardiographic parameters usually assessed in mitral disease, the three principal atrial diameters were also measured in each patient, both preoperatively and postoperatively. The anteroposterior diameter of the LA was measured along the parasternal axis and the mediolateral and superoinferior LA diameters were measured from the apical four-chamber view. The LA surface area was determined echocardiographically from the apical four-chamber view and the atrial volume was calculated by applying the standard formula for an ellipse.[9] The contribution to left ventricular filling made by the atrium was evaluated postoperatively by Doppler echocardiography to determine peak contraction velocity of the atrium (i.e., the A wave), protodiastolic filling velocity of the atrium (i.e., the E wave), and the ratio of A to E. All measurements were made at the end of ventricular systole. In the present study, postoperative atrial size was regarded as normal if the postsurgical volumes of the right and left atria were both less than 65 mL and the LA-volume-to-body-height ratio was less than 42 mL/m. Some authors prefer to use the atrial-volume-to-body-height ratio in long-term studies because it helps compensate for body surface area variations caused by changes in the patient's weight.10 In our study, no significant preoperative differences between the two groups were detected echocardiographically, as can be seen in Table 2.

Electrocardiographic and echocardiographic assessments were carried out 3, 6, 12, 24 and 36 months after the operation. During the first 3 months, all patients received amiodarone 200 mg/day orally, or, if contraindicated, sotalol 80-160 mg/day orally. Antiarrhythmic medication was subsequently withdrawn in patients who attained sinus rhythm. Anticoagulation therapy was discontinued after mitral repair or placement of a mitral bioprosthesis, once atrial contractions were observable echocardiographically. Episodes of persistent AF or atrial flutter that occurred during follow-up were treated with external cardioversion, with a maximum of three cardioversions from the day of discharge from hospital. No more than three cardioversions were carried out as it was thereafter assumed that the postoperative AF was permanent and that antiarrhythmic surgery had been ineffective. The mean follow-up period was 31±18 months, during which no patient withdrew from the study.

Data are reported as the mean±standard deviation (SD). The intergroup statistical analysis was carried out using a nonparametric Mann-Whitney test for quantitative variables and the Fisher exact test for qualitative variables. Comparison of means during the postoperative period was carried out using the Mann-Whitney test for two means and the Friedman test for three or more means. Kaplan-Meier survival curves were calculated using a log rank test to compare mortality curves. The minimum acceptable level of significance was $P<.05$.

TABLE 2. **Comparison of the principal preoperative atrial echocardiographic parameters and dimensions in the two groups**

	Group I	Group II
Right ventricle, mm	17.0±3.6	16.9±0.5
Ventricular septum during diastole, mm	9.5±1.8	10.0±2.5
Ventricular septum during systole, mm	13.8±2.2	16.0±7.0
LV end-diastolic diameter, mm	50.9±5.9	50.5±8.2
LV end-systolic diameter, mm	30.4±5.3	33.5±6.9
LV fractional shortening, %	40.0±5.4	35.9±8.1
Pulmonary artery systolic pressure, mm Hg	54.8±12.0	60.5±17.3
LA anteroposterior diameter, mm	57.9±12.2	57.1±11.5
LA mediolateral diameter, mm	62.3±19.4	60.5±16.8
LA superoinferior diameter, mm	79.7±15.4	76.6±12.8
LA surface area, cm^2	42.3±22.0	42.1±15.6
LA volume, mL	169.2±127.2	154.1±99.7
LA-volume-to-body-height ratio, mL/m	107.6±82.5	96.8±61.6
RA anteroposterior diameter, mm	39.8±6.9	46.2±12.9
RA superoinferior diameter, mm	56.9±7.7	53.2±9.9
RA surface area, cm^2	18.3±2.6	20.7±4.8
RA volume, mL	46.1±17.1	66.1±39.5
RA-volume-to-body-height ratio, mL/m	30.3±10.0	40.9±22.0

LV indicates left ventricle; LA, left atrium; RA, right atrium.

RESULTS

A total of 38 valve replacements and 12 valve repairs were carried out. The decision whether to replace or repair a valve was based of the type of mitral disease and the patient´s age. As can be seen in Table 1, there were no statistically significant differences between the groups in terms of the type of mitral surgery performed or in postoperative morbidity or mortality. Four patients died during follow-up. A 77-year-old patient in group I, who was in sinus rhythm at his last follow-up assessment, died from unknown causes after 3 years. In group II, a 70-year-old patient in AF died from a respiratory infection in the fourth month of follow-up. A second group II patient in AF, aged 48 years, died after 3 months from a cardiac arrest that was probably due to inappropriate anticoagulant therapy, and the third group II patient, who was 54 years old and in AF, died after 31 months from unknown causes. At the end of follow-up the survival rate was 82% in group I and 88% in group II. A comparison of survival curves showed no statistically significant difference in mortality between

TABLE 3. **Relationship between atrial rhythm and left atrial volume at discharge**

	Group I		Group II	
	SR	AF	SR	AF
LA volume				
<65 mL	6	7	1	6
>65 mL	3	9	5	13
LA-volume-to-body-height ratio				
<42 mL/m	6	8	2	8
>42 mL/m	3	8	4	11

There were no significant differences between the groups.
SR indicates sinus rhythm; AF, atrial fibrillation; LA, left atrium.

groups. Nor were there any significant differences in postoperative functional grade, as assessed using the NYHA classification. The number of thromboembolic events that occurred during follow-up was very low. There was only one thromboembolic episode in a patient in group II who was in AF, probably caused by an error in anticoagulant intake.

The surgical atrial reduction that was carried out along with mitral surgery had electrophysiologic implications: a greater number of patients in group I recovered sinus rhythm after the operation. Although there were no statistically significant differences between the groups at discharge, there was some relationship between atrial rhythm and LA size postoperatively, as can be seen in Table 3. By the third month of follow-up, 15 patients (60%) in group I were in sinus rhythm, a significantly higher percentage (P=.03) than in group II, in which five patients (21%) recovered sinus rhythm. During clinical follow-up, the number of patients in sinus rhythm declined in both groups, as shown in Table 4. At the end of the study, 46% of patients in group I were in sinus rhythm compared with 18% in group II (P=.06).

Echocardiographic investigation of atrial contractile function in patients who recovered sinus rhythm showed that nine patients in group I had contractions in both atria (transmitral A wave, 0.81±0.48 m/s; A:E ratio=0.65±0.31) and two had atonic atria. Among patients in group II who were in sinus rhythm, three recovered contractile function in both atria (transmitral A wave, 0.91(0.31 m/s; A:E ratio, 0.62±0.24) and one failed to develop effective contractions.

TABLE 4. **Patients in sinus rhythm during follow-up**

	Group I	Group II	*P*
Sinus rhythm			
At discharge (n=25/25)	9 (36%)	6 (24%)	NS
Postoperative month			
3 (n=25/24)	15 (60%)	5 (21%)	.03
6 (n=25/23)	13 (52%)	8 (34%)	NS
12 (n=25/23)	11 (44%)	6 (26%)	NS
18 (n=25/23)	11 (44%)	4 (17%)	.06
End of follow-up (31±18 months), (n=24/22)	11 (46%)	4 (18%)	.06

n indicates patients in group I/patients in group II.

Atrial remodeling

In our study we distinguished between two different types of remodeling: surgical, or immediate postoperative remodeling, and long-term postoperative remodeling.

A shown in Table 5, the extent of surgical atrial remodeling depended on the surgical technique employed. The postoperative LA volume and the LA-volume-to-body-height ratio were both significantly lower (P<.05) in group I patients than in group 2. Therefore, the atrial tissue surface area available for sustaining AF was smaller in group I after the operation. The mean LA volume decreased by 55% in group I from a preoperative value of 169.2±127.2 mL to a postoperative value of 76.2±35.2 mL. However, it was not possible to normalize LA size in 12 patients, who continued to have echocardiographically measured LA volumes greater than 65 mL. In patients in group II, the mean LA volume also decreased postoperatively, by 28.1%. In this group the reduction in LA volume was due to tissue plication that occurred during finalization of atrial surgery and not to surgical atrial reduction, as in group I. Although, by definition, surgical reduction of the right atrium (RA) was not performed in this study, the mean postoperative volume of the RA was reduced in both patient groups: by 9.7% in group I and by 11.4% in group II (no significant difference). Only the RA-volume-to-body-height ratio was significantly different (P=.04) between the groups, as can be seen in Table 5.

The extent of the long-term atrial remodeling that occurred during the follow-up period from the day of hospital discharge depended on the nature of the atrial rhythm established after surgery and on postoperative atrial size. Atrial size decreased (i.e., there was reverse remodeling) in all patients who recovered sinus rhythm, irrespective of the type of surgery performed, as can be seen in Table 6. The LA volume reduction was greater in group II patients in sinus rhythm than in equivalent patients in group I, with a mean reduction of 21.5% in group II versus 10.8% in group I (P<.05). It appears that if sinus rhythm is maintained, atrial size reduction occurs more readily when the atrium has not been surgically reduced (i.e., in group II) than when atrial surgery has been performed (i.e., in group I). The atrial became steadily smaller during the first 6 months after the operation until a final size was reached, as can be seen in Figure 1. In contrast, atrial dilatation began anew in patients who remained in AF, especially in those in group I. There was a mean dilatation of 16.8% in group I patients in AF compared with a mean dilatation of 8.4% in equivalent patients in group II (P<.05). Three months

TABLE 5. **Comparison of postoperative atrial dimensions in the two groups at discharge**

	Group I	Group II	*P*
LA anteroposterior diameter, mm	46.1±7.8	51.7±1.2	.05
LA mediolateral diameter, mm	49.0±8.8	56.7±13.8	.01
LA superoinferior diameter, mm	59.9±14	64.4±14.2	.25
LA surface area, cm^2	28.7±7.8	35.7±5.3	.07
LA volume, mL	76.2±35.2	11.7±86.3	.05
LA-volume-to-body-height ratio, mL/m	48.2±22.4	71.9±55.3	.04
LA volume			.14
<65 mL, n	13	7	
>65 mL, n	12	18	
RA anteroposterior diameter, mm	37.5±6.8	45.8±11.9	.02
RA superoinferior diameter, mm	54.3±7.4	5.2±7.5	NS
RA surface area, cm^2	17.6±4.4	18.7±6.0	NS
RA volume, mL	41.6±19.4	58.5±3.2	.1
RA-volume-to-body-height ratio, mL/m	26.1±11.5	35.7±17.7	.04
RA volume, mL			
<65 mL, n	10	18	.2
>65 mL, n	1	10	
LA volume change, %	-55%	-28.1%	
RA volume change, %	-9.7%	-11.4%	

LA indicates left atrium; RA, right atrium.

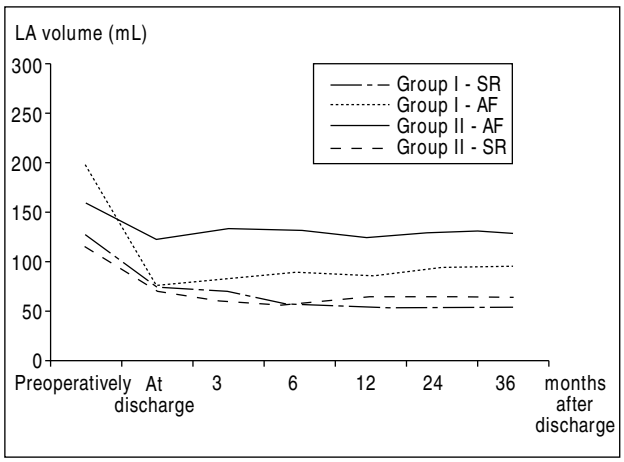

Fig. 1. Changes in left atrial volume observed echocardiographically during follow-up. Patients are divided according to experimental group and postoperative atrial rhythm. AF indicates atrial fibrillation; SR, sinus rhythm.

after the operation, statistically significant differences in LA size were observed between patients in group I in sinus rhythm and those in AF, and significant differences (P<.05) were maintained until the end of the follow-up period. This did not occur in group II patients.

Throughout follow-up, the RA also underwent remodeling similar to that in the LA. In group I patients in sinus rhythm, the RA became progressively smaller and there was a mean volume reduction of 9.7%. In those in AF, dilatation occurred and there was a mean increase in volume of 6.2%. In group II, a mean volume reduction of 13% was observed in patients in sinus rhythm but dilatation was observed in those in AF, corresponding to a mean volume increase of 2.2% (Table 6).

DISCUSSION

The atria are anatomical structures that are able, over time, to adapt to various pathophysiologic mechanisms that can act upon them. Experimental work by Allessie et al[1,11-13] demonstrated how rapidly varying stimulation of the atrium can modify the electrophysiologic properties of tissues. The result is a shortening of the atrial refractory period, which makes the induction and maintenance of AF more likely. This process has been termed atrial electrical remodeling. The concept of

TABLE 6. **Long-term atrial remodeling. Changes in atrial dimensions at the end of follow-up, categorized according to atrial rhythm**

	Group I		Group II	
	Patients in SR (n=9)	Patients in AF (n=15)	Patients in SR (n=4)	Patients in AF (n=18)
Δ LA anteroposterior diameter, mm	−1.0±7.9	+3.2±4.8	−1.2±4.1	+2.7±5.6
Δ LA mediolateral diameter, mm	−1.1±6.5	+4.4±9.1	−4.7±8.2	+0.37±9.2
Δ LA superoinferior diameter, mm	−0.2±13.2	+0.8±3.2	−6.0±10.9	+1.9±8.6
Δ LA surface area, cm^2	−2.3±2.4	+4.3±13.4	−4.6±4.0	−0.3±5.6
Δ LA volume, mL	−8.9±14	+13.1±33.9	−15.4±15.3	+10.4±34.3
Δ LA-volume-to-body-height ratio, mL/m	−5.0±8.5	+9.7±21.1	−10.0±11.0	+7.1±23.5
Δ RA surface area, cm^2	−2.7±3.2	+0.5±3.7	+1.6±6.6	+1.3±4.2
Δ RA volume, mL	−9.3±13.8	+6.6±21.3	+8.6±16.0	+1.3±24.6
Δ RA-volume-to-body-height, mL/m	−6.1±8.2	+4.3±13.1	+5.7±9.6	+1.6±14.8
LA volume change, %	−10.8%	+16.8%	−21.5%	+8.4%
RA volume change, %	−9.7%	+6.2%	−13%	+2.2%

SR indicates sinus rhythm; AF, atrial fibrillation; LA, left atrium; RA, right atrium.

remodeling embraces a number of different forms of atrial modification, including electrophysiologic, histologic and anatomic alterations.[1,3,4,14] Katz et al described three stages in the process of atrial electrical remodeling, which relate to whether alterations occur in ion channels or whether there are cellular or structural alterations. Mitral valve disease and permanent AF result in histologic changes, which are often irreversible, and in atrial enlargement. This process is termed anatomic or structural remodeling.[4,15] In the present study, the patients all had mitral disease requiring surgery and were in AF. On presentation before their operations, they had LA enlargement, which was observed to be proportional and of almost equal magnitude along the three spatial axes. Each axial dimension was approximately 20 mm larger on average than that found in the general population.[9] The mean preoperative LA volume was approximately three times greater than normal and the mean RA volume was 1.5 times greater

Few studies describing postoperative atrial remodeling in patients who have undergone surgery for mitral disease have been reported in the literature. As we were able to demonstrate in our group II patients, mitral surgery is itself associated with an immediate postoperative reduction in atrial size, which is caused by the tissue plication that occurs during surgical closure of the atrium. Obadia et al[16] studied 191 patients who underwent surgery for mitral disease that did not include surgical reduction of the atrium. The researchers observed an immediate postoperative decrease in mean LA size of 8 mm. The mean preoperative anteroposterior diameter was 52.8 mm and the mean postoperative diameter was 44.8 mm. This decrease in LA size is close to the average decrease of 5.4 mm observed in the control patients in group II in our study. Chen et al7 reported similar findings in 119 patients in AF who underwent surgery for valve disease and who were treated using the radiofrequency ablation Maze procedure. In addition, they observed significant reductions in the size of both atria during the first 3 months after the operation in those who recovered sinus rhythm. Chua et al[17] reported smaller reductions in LA size after mitral surgery in 97 patients in permanent AF, with a postoperative decrease in mean anteroposterior diameter of only 3.5 mm. In our study, the magnitude of surgical remodeling was greater in patients in group I, in whom surgical reduction of the atrium was also performed. The mean LA anteroposterior diameter decreased by 11.8 mm and there was a 55% reduction in mean LA volume compared with the preoperative value. Moreover, atrial size normalized in 52% of patients. The mean LA volume also decreased postoperatively in our group II patients, by 28.1%. These findings suggest that the decrease in LA size in group I patients could have been due to plication as well as to surgical atrial reduction. Approximately half of the mean LA volume reduction of 55% that occurred in group I patients could have been the result of the plication that occurred during surgical closure of the atrium. In our study, the postoperative atrial volume was related to the magnitude of the initial volume and to the surgical technique employed. Surgery of the posterior atrial wall was not able to normalize atrial size in patients with very large atria. We believe that, if atrial size is to be successfully normalized by surgery, the nature of the surgical reduction performed must be individually matched to each patient on the basis of preoperative atrial size.

Although it is difficult to explain why RA size decreased immediately after the operation, a number of mechanisms can be proposed: there may have been decreased pressure in the right heart chambers after mitral repair; part of the free wall of the RA may have been compromised and plicated during surgical closure of the LA; or the RA may have been displaced by traction caused by LA size reduction. We believe that the significant decrease in the anteroposterior diameter of the RA that occurred in our group I patients supports the suggestion that a displacement mechanism was responsible. The anteroposterior RA diameter was 37.5±6.8 mm in group I patients compared with 45.8±11.9 mm in group II patients (P=.02).

The long-term atrial remodeling that occurs in patients after mitral surgery is the result of several factors, the most important of which are correction of the valve disease, the nature of the atrial rhythm after the operation, and the degree of reversibility of the histologic lesions. The process of atrial electrical remodeling described by Allessie[1] and Wijffels[13] has been demonstrated clinically by several authors. In a study of 15 patients with idiopathic AF, Sanfilippo et al observed atrial dilatation during 20 months of follow-up, with the mean LA volume increasing from 45.2 mL to 64.1 mL and the mean RA volume, from 49.2 mL to 66.2 mL (P<.001).[15] In our study, we documented renewed atrial dilatation throughout the 31 months of follow-up in patients who remained in AF postoperatively. The magnitude of atrial dilatation was greater in group I patients. However, at the end of follow-up, the mean LA size in patients in AF was still less than it was preoperatively. The final reduction in mean LA volume in patients in group I was 50% and, in group II patients, 14.5%. Although it is difficult to be certain which mechanism was most responsible for the long-term remodeling that took place in our study, we believe that it can largely be attributed to AF-induced atrial electrical remodeling.

The fact that AF induces a process of atrial remodeling suggests that a reverse remodeling process may occur when sinus rhythm is regained. In fact, this process is termed reverse atrial remodeling.[1] Avitall et al[18] demonstrated reverse anatomic remodeling in an experimental model that involved dogs in permanent AF. They found that the mean LA surface area, as assessed echocardiographically, decreased by 40% in the 5

months after recovery of sinus rhythm. Pappone et al[19] studied 49 patients with a history of permanent AF who recovered sinus rhythm after selective ablation of pulmonary veins. They observed a mean LA size decrease of 5.2 mm after 10 months of follow-up. In 29 patients who remained in AF, the mean decrease was 2.6 mm. In our study, after 31 months of follow-up, reverse remodeling manifested as volume reductions in both atria, which mainly occurred during the first 6 months after the operation. The atria reached stable postoperative dimensions during this period. LA volume regression was greater in patients in the control group. By the end of follow-up, the final mean LA volume decrease in patients in group I who recovered sinus rhythm was 60.2% and, in the control group, 38.1%.

Currently, many aspects of mitral surgery are still poorly understood. We do not know how atrial dilatation influences postoperative morbidity and mortality over the long-term, though it is known that atrial dilatation favors hemostasis and thrombus formation, and, because the surface area of atrial tissue is increased, encourages and sustains AF. We believe that reducing and normalizing the size of the atrium during mitral surgery can have benefits. As we reported in a previously published study, a large number of patients undergo surgical ablation for AF. Kosakai[20] has collected data on the largest series of patients who have undergone the maze procedure that has been reported in the scientific literature, totaling 2547 patients who underwent interventions at 517 hospitals in Japan. The observation that the success rate of the maze procedure was less than 60% in patients with anteroposterior LA diameters greater than 70 mm led to a recommendation that these patients should also undergo surgical atrial reduction. Other groups agree and have also recommended that atrial tissue should be removed during the maze procedure.[21-23] Moreover, normal atrial size appears to be associated with less long-term morbidity and mortality. The Framingham population study showed that atrial size is one of the most important risk factors for stroke and death. The risk doubles for every 10-mm increase in La size.[24] In addition, The Stroke Prevention in Atrial Fibrillation (SPAF)[25] study identified LA dilatation and left ventricular dysfunction as echocardiographic predictors of arterial thromboembolism in non-rheumatic AF. Although it is not strictly correct to extrapolate from these studies, there is hope that patients who have a normal LA volume after surgery will experience less long-term morbidity and mortality. In our study, it was not possible to observe these anticipated clinical consequences of atrial remodeling because our sample size was small and the follow-up period was short.

Our study had a number of limitations, the principal of which was probably the restricted number of patients. Another limitation was that the study included only patients with mitral valve disease and permanent AF. It is difficult to extrapolate the findings to other forms of AF associated with other types of heart disease. This study employed the technique of echocardiography to monitor and investigate the atrial remodeling process. Measurement variability is an important problem, especially when diameters are measured to the millimeter. And, even though all measurements were carried out by the same echocardiographers, technical errors are unavoidable. Nevertheless, this was a randomized study and it can, therefore, be assumed that errors were evenly distributed between the two groups. It is likely that newer diagnostic techniques, such as magnetic resonance imaging, are more appropriate for studying atrial remodeling.

CONCLUSIONS

From the data collected in the present study, we conclude that the size of both atria usually decrease after mitral surgery in a process we have called postsurgical atrial remodeling. Patients with a history of permanent AF who recover sinus rhythm after the operation exhibit a decrease in atrial size throughout follow-up. This is mainly attributable to the process of atrial electrical remodeling, in addition to other factors. However, patients who remained in AF after the operation experienced renewed atrial dilatation, which mainly developed during the first six months of follow-up. Despite this renewed dilatation in patients who remained in AF, the atrial size was still less than it was preoperatively. If mitral surgery is combined with surgical reduction of the atrium, there is an increased likelihood that surgery will eliminate AF. In addition, the final atrial volume will be less and the morbidity and mortality associated with increased atrial size will probably also be reduced.

REFERENCES

1. Allessie MA. Atrial electrophysiologic remodeling: another vicious circle? J Cardiovasc Electrophysiol 1998;9:1378-93.
2. Daoud EG, Bogun F, Goyal R, Harvey M, Man C, Strickberger SA. Effect of atrial fibrillation on atrial refractoriness in humans. Circulation 1996;94:1600-6.
3. Ausma J, Wijffels M, van Eys G, Koide M, Ramaekers F, Allessie M, et al. Dedifferentiation of atrial cardiomyocytes as a result of chronic atrial fibrillation. Am J Pathol 1997;151:985-97.
4. Ausma J, Wijffels M, Thone F, Wouters L, Allessie M, Borgers M. Structural changes of atrial myocardium due to sustained atrial fibrillation in the goat. Circulation 1997;96:3157-63.
5. Katz AM. T wave «memory» possible causal relationship to stress-induced changes in cardiac ion channels? J Cardiovasc Electrophysiol 1992;3:150-9.
6. Allessie MA. Atrial fibrillation-induced electrical remodeling in humans. What is the next step? Cardiovasc Res 1999;44:10-2.
7 Chen MC, Chang JP, Guo BF, Chang HW. Atrial size reduction as a predictor of the success of radiofrequency maze procedure for chronic atrial fibrillation in patients undergoing concomitant

valvular surgery. J Cardiovasc Electrophysiol 2001;12:867-74.
8. Hornero F, Atienza F, Montero JA, Gil O, García R, Paya R, et al. Auriculectomía parcial izquierda en el tratamiento de la fibrilación auricular por valvulopatía mitral. Rev Esp Cardiol 2001; 54:703-8.
9. Weyman AE. Left ventricular inflow tract II: the left atrium, pulmonary veins, and coronary sinus. En: Principles and practice of echocardiography. 2nd ed. Philadelphia: Lea and Febiger, 1994; p. 471-9.
10. Gottdiener J, Reda D, Williams DW, Materson B, Cushman W, Anderson R. Effect of single-drug therapy on reduction of left atrial size in mild to moderate hypertension. Circulation 1998;98: 140-8.
11. Wijffels M, Kischhof CJ, Dornald R, Allessie MA. Electrical remodeling due to atrial fibrillation in chronically instrumented conscious goats: roles of neurohumoral changes, ischemia, atrial strech and high rate of electrical activation. Circulation 1997; 96:3710-20.
12. Allessie MA, Konings K, Kirchhof CJ, Wijffels M. Electrophysiologic mechanisms of perpetuation of atrial fibrillation. Am J Cardiol 1996;77:A10-23.
13. Wijffels M, Kirchhof CJ, Dornald R, Allessie MA. Atrial fibrillation begets atrial fibrillation: a study in awake chronically instrumented goats. Circulation 1995;92:1954-68.
14. Leistad E, Christensen G, Ilebekk A. Effects of atrial fibrillation on the left and right atrial dimensions, pressures, and compliance. Am J Physiol 1993;264:H1093-7.
15. Sanfilippo AJ, Abascal VM, Sheehan M, Oertel LB, Harrigan P, Hughes RA, et al. Atrial enlargement as a consequence of atrial fibrillation. A prospective echocardiographic study. Circulation 1990;82:792-7.
16. Obadia JF, Farra M, Bastien OH, Lievre M, Martelloni Y, Chassignolle JF. Outcome of atrial fibrillation after mitral valve repair. J Thorac Cardiovasc Surg 1997;114:179-85.
17. Chua YL, Schaff HV, Orszulak TA, Morris JJ. Outcome of mitral valve repair in patients with preoperative atrial fibrillation. Should the maze procedure be combined with mitral valvuloplasty? J Thorac Cardiovasc Surg 1994;107:408-15.
18. Avitall B, Urbonas A, Urboniene D, Millard S, Helms R. Time course of left atrial mechanical recovery after lesions: normal sinus rhythm versus chronic atrial fibrillation dog model. J Cardiovasc Electrophysiol 2000;11:1406.
19. Pappone C, Oreto G, Rosanio S, Vicedomini G, Tocchi M, Gugliotta F, et al. Atrial electroanatomic remodeling after circumferential radiofrequency pulmonary vein ablation. Efficacy of an anatomic approach in a large cohort of patients with atrial fibrillation. Circulation 2001;104:2539-44.
20. Kosakai Y. Treatment of atrial fibrillation using the maze procedure: the japanese experience. Semin Thorac Cardiovasc Surg 2000;12:44-52.
21. Melo JQ, Adragao P, Aguiar C, Neves AC, Ferreira MM, Teles R, et al. Bilateral pulmonary veins isolation by intraoperative radiofrequency ablation for atrial fibrillation surgery [abstract]. Pacing Clin Electrophysiol 1999;22:893.
22. Sankar NM, Farnsworth AE. Left atrial reduction for chronic atrial fibrillation associated with mitral valve disease. Ann Thorac Surg 1998;66:254-6.
23. Kamata J, Kawazoe K, Izumoto H, Kitahara H, Shiina Y, Sato Y, et al. Predictors of sinus rhythm restoration after Cox maze procedure concomitant with other cardiac operations. Ann Thorac Surg 1997;64:394-8.
24. Benjamin EJ, D'Agostino RB, Belanger AJ, Wolf PA, Levy D. Left atrial size and the risk of stroke and death. The Framingham Heart Study. Circulation 1995;92:835-41.
25. The Stroke Prevention in Atrial Fibrillation Investigators. Predictors of thromboembolism in atrial fibrillation: II. Echocardiographic features of patients at risk. Ann Intern Med 1992;116:6-12.