Recovery of Atrial Function After Atrial Compartment Operation for Chronic Atrial Fibrillation in Mitral Valve Disease

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Objectives. We prospectively studied the recovery of atrial function after atrial compartment operation and mitral valve surgery in patients with chronic atrial fibrillation caused by mitral valve disease.

Background. Chronic atrial fibrillation is the most common arrhythmia in mitral valve disease. This arrhythmia is associated with excessive morbidity and mortality. Mitral valve surgery alone rarely eliminates it.

Methods. Twenty-two patients underwent mitral valve surgery and a new surgical method, atrial compartment operation. Doppler echocardiography was performed in all patients before operation and at 1 week and 2 and 6 months after operation in the successful cardioversion group. Peak early diastolic (E) and atrial (A) filling velocities, peak A/E velocity ratio and A/E integral ratio of the mitral and tricuspid valves were measured.

Results. Sinus rhythm was restored immediately after operation in 91% of patients and was maintained for >1 week in 15 (68%) of 22 patients and >6 months in 14 (64%) of 22. Eleven of 15 patients had left atrial paralysis (A/E integral ratio 0) at 1 week and 6 of 14 patients at 2 months. Nine of 15 patients had right atrial paralysis (A/E integral ratio 0) at 1 week and 1 of 14 patients at 2 months. Both left and right atrial contractile function (presence of an A wave on Doppler findings) was detected at 6 months in 14 patients. Mean (±SD) peak atrial filling velocity of the mitral valve was 15 ± 26 cm/s at 1 week, 38 ± 39 cm/s at 2 months and 93 ± 32 cm/s at 6 months (p < 0.001). Mean peak atrial filling velocity of the tricuspid valve was 14 ± 19 cm/s at 1 week, 33 ± 19 cm/s at 2 months and 50 ± 19 cm/s at 6 months (p < 0.001). Peak early diastolic and atrial filling velocities, peak A/E velocity ratio and A/E integral ratio of the mitral and tricuspid valves increased significantly from 1 week to 6 months.

Conclusions. Chronic atrial fibrillation in mitral valve disease can often be eliminated by atrial compartment operation. No surgical mortality or significant complications were encountered. Both left and right atrial function, as manifested by Doppler findings, recover after compartment operation and improve over time. The mechanical function of the right atrium recovers earlier than that of the left.

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detailed about the experimental nature of the surgical procedure and its possible risk; all provided written informed consent. Underlying heart disease included rheumatic mitral valve disease in 15 patients, rheumatic mitral and aortic valves disease in 1 and nonrheumatic mitral regurgitation in 6. All patients were symptomatic; 20 were in New York Heart Association functional class III; 2 were in class IV. The onset of atrial fibrillation was counted as the date of the first electrocardiogram (ECG) showing this arrhythmia. The duration of atrial fibrillation ranged from 0.5 to 5 years, with a mean duration of 2.5 years. Successful surgical cardioversion was defined as maintenance of stable sinus rhythm for >1 week after surgery. No antiarrhythmic drugs were given to patients who maintained sinus rhythm >1 week. Anticoagulant agent was given for at least 3 months after operation. The medications before and after operation were the same except for antiarrhythmic drugs. All patients had digitalis and diuretics. Angiotensin-converting enzyme inhibitor was given to four patients.

Follow-up. Postoperative care was the same as for routine open heart surgery. Electrocardiographic monitoring was used to detect recurrence of atrial fibrillation postoperatively in the 1st 3 days in the surgical intensive care unit. An ECG was taken for the 1st 3 days after operation and on the day of discharge. All patients visited the outpatient clinic every 2 weeks for the 1st 3 months and every 4 weeks thereafter. Electrocardiographic and 24-h Holter monitoring were used to detect sinus rhythm in all patients.

Echocardiography. Baseline echocardiographic (M-mode and Doppler) study was performed <1 week before operation. Repeated echocardiographic studies were performed at 1 week and 2 and 6 months after operation in patients with successful conversion of atrial fibrillation. All echocardiograms were recorded by use of a Toshiba SSH-65A ultrasound system with a 2.5-MHz precordial transducer. Two-dimensional echocardiographic images were recorded in the parasternal, apical and subcostal views. Left atrial and left ventricular end-diastolic and end-systolic dimensions were measured on an M-mode tracing taken from a two-dimensional parasternal long-axis view. Transmitral pulsed Doppler examination was performed from the apical four-chamber view and during quiet respiration. The Doppler sample volume was placed at the tips of the mitral valve during diastole. Transtricuspid pulsed Doppler examination was performed from the right ventricular inflow view. The sample volume was placed at the tips of the tricuspid valve during diastole. The Doppler beam was aligned perpendicular, or nearly perpendicular, to the plane of the mitral and tricuspid annuli. No angle correction of the Doppler signals was made. The Doppler signals of the transmitral and transtricuspid inflows were optimized by using audio output. Maximal velocity and velocity time integral of the atrial diastolic filling phase were calculated from the spectral Doppler tracing when an A wave was identifiable. The percent of atrial contribution to total diastolic transmural flow was calculated. Observers traced the modal velocities, and when the margins of the waveforms were indistinct, they ignored the noise artifact and traced the highest portions of the waveform margin. When there was overlap between the E and A waves, the descending limb of the E wave was extrapolated to the zero line to define the E wave flow velocity integral, and the rest of the tracing was considered A wave. Average values of five consecutive cardiac cycles were used for analysis. All echocardiograms were reviewed independently by two observers, who were unaware of the time since operation during the analysis. The calculations of both observers were averaged.

Surgical procedure. After institution of cardiopulmonary bypass and hyperkalemic cardioplegia protection, mitral valve surgery was performed. After the routine valve operation, the left atrium was opened behind the interatrial sulcus (A) when the three-compartment operation was performed. In addition to procedure A, the right atrium at 1 cm medial and parallel to the sulcus terminalis was incised (B) when the three-compartment operation was performed. AVN = atrioventricular node; IVC = inferior vena cava; LIPV = left inferior pulmonary vein; LSPV = left superior pulmonary vein; LV = left ventricle; RV = right ventricle; SN = sinus node; SVC = superior vena cava.
the right atrial free wall was left intact. The atrial fibers behind the coronary sinus and at the lower margin of right atrial incision were preserved as the electrical connection between compartments. No defibrillation was done during or after operation.

**Statistical analysis.** Data are expressed as mean value ± 1 SD. Categoric variables were analyzed with the Fisher exact test. Continuous variables were analyzed by means of \( t \) test and analysis of variance with Scheffé posteriori comparison; \( p < 0.05 \) was considered significant.

### Results

Surgical conversion of atrial fibrillation. All patients except two underwent conversion to sinus rhythm by atrial compartment operation immediately after operation. Electrical cardioversion was attempted in these two patients at the end of the surgical procedure after failure of surgical cardioversion; however, atrial fibrillation was not yet converted to sinus rhythm. Five patients had recurrence of atrial fibrillation in 6 days. A successful surgical cardioversion with >1 week maintenance of sinus rhythm was achieved in 15 patients. Atrial fibrillation recurred in one patient 46 days after operation. Maintenance of sinus rhythm >6 months was observed in 14 patients. Age, gender, duration of atrial fibrillation, left atrial diameter, severity of heart failure, etiology of mitral valve disease, surgical methods, concomitant surgical method and mode of atrial fibrillation were not significantly different between those who remained in atrial fibrillation and those who converted to sinus rhythm (Table 1). Left atrial size or chronicity of atrial fibrillation had no association with maintenance of sinus rhythm.

**Surgical results.** Mitral valve repair was performed in 16 patients (10 with successful cardioversion, 6 with failed cardioversion) and mitral valve replacement in 6 patients (5 with successful cardioversion, 1 with failed cardioversion). Two- and three-compartment operations were performed in eight and seven patients, respectively, with successful cardioversion. In patients with failed cardioversion, the two-compartment operation was performed in five and the three-compartment operation in two. Left atrial thrombus was found in one patient in each group, and left atrial appendage obliteration was done. Other concomitant surgical methods included coronary artery bypass graft in one patient and tricuspid valve repair in two with successful cardioversion and aortic valve replacement in one patient with failed cardioversion. No surgical mortality or significant complication was encountered in any patient. Each patient had a mitral valve area >2.0 cm\(^2\) postoperatively.

**Change in mitral inflow pattern.** No mitral A wave was identifiable by Doppler echocardiography in any patient before cardiac surgery. In patients with successful cardioversion, no mitral A wave was detectable in 11 at 1 week or in 6 at 2 months after operation. However, mitral A wave was detected in 14 patients at 6 months after operation. The peak early diastolic and atrial filling velocities of the mitral valve increased gradually from 1 week to 6 months after operation (Table 2). There was no significant change in heart rate at 1 week and at 2 and 6 months. The magnitude of increase in early diastolic filling velocity was less than that of atrial filling velocity. Consequently, the peak A/E ratio increased from 1 week to 6 months. The A/E integral ratio also increased from 1 week to 6 months (Fig. 2 and 3). Eleven of 15 patients had left atrial paralysis (A/E integral ratio 0) at 1 week and 6 of 14 patients at 2 months. There was no significant change in left atrial size at 1 week and at 2 months or 6 months (44 ± 8, 43 ± 9 and 44 ± 6 mm, respectively).

### Table 1. Factors Influencing Successful Conversion of Chronic Atrial Fibrillation by Compartment Operation

<table>
<thead>
<tr>
<th>Factor</th>
<th>Success (n = 15)</th>
<th>Failure (n = 7)</th>
<th>p Value</th>
</tr>
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<tbody>
<tr>
<td>Age (yr)</td>
<td>41 ± 16</td>
<td>47 ± 9</td>
<td>NS</td>
</tr>
<tr>
<td>Duration of AF (yr)</td>
<td>2.5 ± 3.0</td>
<td>2.6 ± 1.2</td>
<td>NS</td>
</tr>
<tr>
<td>LA diameter (mm)</td>
<td>53 ± 10</td>
<td>51 ± 3</td>
<td>NS</td>
</tr>
<tr>
<td>NYHA functional class</td>
<td>3.1 ± 0.3</td>
<td>3.1 ± 0.4</td>
<td>NS</td>
</tr>
<tr>
<td>Gender (M/F)</td>
<td>5/7</td>
<td>3/2</td>
<td>NS</td>
</tr>
<tr>
<td>Etiology (RHD/non-RHD)</td>
<td>11/4</td>
<td>6/2</td>
<td>NS</td>
</tr>
<tr>
<td>Surgical methods (2-C/3-C)</td>
<td>8/7</td>
<td>5/2</td>
<td>NS</td>
</tr>
<tr>
<td>Concomitant surgery (MVR/MVP)</td>
<td>5/10</td>
<td>1/6</td>
<td>NS</td>
</tr>
<tr>
<td>Mode of AF (fine/course)</td>
<td>4/11</td>
<td>1/6</td>
<td>NS</td>
</tr>
</tbody>
</table>

AF = atrial fibrillation; course = fibrillation wave in electrocardiographic (ECG) lead V1 >0.1 mV; fine = fibrillation wave in ECG lead V1 <0.1 mV; LA = left atrium; MVR = mitral valve replacement; MVP = mitral valve repair; NYHA = New York Heart Association; RHD = rheumatic heart disease; 2-C = two-compartment; 3-C = three-compartment.

### Table 2. Change in Transmitral Inflow Patterns in Patients With Long-Term Maintenance of Sinus Rhythm

<table>
<thead>
<tr>
<th>Time</th>
<th>E (cm/s)</th>
<th>A (cm/s)</th>
<th>Peak A/E Velocity Ratio</th>
<th>A/E Integral Ratio</th>
<th>HR (beat/min)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1 wk</td>
<td>106 ± 26</td>
<td>15 ± 26</td>
<td>0.14 ± 0.24</td>
<td>0.08 ± 0.14</td>
<td>80 ± 8</td>
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<tr>
<td>2 mo</td>
<td>120 ± 34</td>
<td>38 ± 39</td>
<td>0.36 ± 0.35</td>
<td>0.18 ± 0.20</td>
<td>83 ± 9</td>
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<tr>
<td>6 mo</td>
<td>143 ± 31*</td>
<td>93 ± 321*</td>
<td>0.63 ± 0.189</td>
<td>0.55 ± 0.19†</td>
<td>82 ± 8</td>
</tr>
</tbody>
</table>

* \( p < 0.01 \) versus 1 week. \( * p < 0.001 \) versus 1 week. \( † p < 0.001 \) versus 2 months. Data presented are mean value ± SD. A = peak atrial filling velocity; E = peak early diastolic filling velocity; HR = heart rate.
Figure 2. Individual change in peak early diastolic (A) and atrial filling velocity (B) of the mitral valve at 1 week and 2 and 6 months (ms) in patients with long-term maintenance of sinus rhythm. Note that no mitral A wave was detectable in 10 and 6 patients at 1 week and 2 months, respectively.

Figure 3. Individual change in peak A/E ratio (A) and A/E integral ratio (B) of the mitral valve at 1 week and 2 and 6 months (ms) in patients with long-term maintenance of sinus rhythm.

Table 3. Change in Tricuspid Inflow Patterns in Patients With Long-Term Maintenance of Sinus Rhythm

<table>
<thead>
<tr>
<th>Time</th>
<th>E (cm/s)</th>
<th>A (cm/s)</th>
<th>Peak A/E Velocity Ratio</th>
<th>A/E Integral Ratio</th>
</tr>
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<tbody>
<tr>
<td>1 wk</td>
<td>56 ± 12</td>
<td>14 ± 19</td>
<td>0.35 ± 0.36</td>
<td>0.20 ± 0.28</td>
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<tr>
<td>2 mo</td>
<td>64 ± 16</td>
<td>33 ± 19</td>
<td>0.55 ± 0.32</td>
<td>0.37 ± 0.22</td>
</tr>
<tr>
<td>6 mo</td>
<td>69 ± 18</td>
<td>50 ± 19*</td>
<td>0.76 ± 0.30*</td>
<td>0.56 ± 0.35*</td>
</tr>
</tbody>
</table>

*p < 0.001 versus 1 week; 1p < 0.05 versus 1 week. Data presented are mean value ± SD. A = peak atrial filling velocity; E = peak early diastolic filling velocity.

Discussion

Atrial fibrillation is the most common arrhythmia complicating mitral valve disease. It is associated with excessive morbidity and mortality. Although surgical correction of mitral valve lesions reduces left atrial size and improves hemodynamic status, once chronic atrial fibrillation develops, mitral valve surgery rarely stops the arrhythmia (3-5). Although new surgical treatments of atrial fibrillation have
Figure 4. Individual change in peak early diastolic (A) and atrial filling velocity (B) of the tricuspid valve at 1 week and 2 and 6 months (ms) in patients with long-term maintenance of sinus rhythm. Note that no tricuspid A wave was identifiable in eight patients at 1 week and in one patient at 2 months.

Figure 5. Individual change in peak A/E (A) and A/E integral ratio (B) of the tricuspid valve at 1 week and 2 and 6 months (ms) in patients with long-term maintenance of sinus rhythm.

been developed to ablate the origin of abnormal impulses on the atrium (12,13), these methods have primarily targeted patients with lone atrial fibrillation. The rationale for atrial compartment operation to stop atrial fibrillation was based on the Moe-Allessie hypothesis (14,15), which confirmed that there are multiple wavelets on the atrium during atrial fibrillation and that a critical mass of the atrium is necessary for the beginning of fibrillation (16). The success of our compartment operation in stopping atrial fibrillation further confirmed this hypothesis. Sinus rhythm was restored in 91% of patients immediately after operation and was maintained >1 week in 68% of patients and >6 months in 64%.

Recovery of atrial mechanical function. Pulsed Doppler echocardiography has usually been used to study left atrial mechanical function after electrical cardioversion of atrial fibrillation (6–8). Recovery of atrial mechanical function was found in most of the patients undergoing electrical cardioversion. However, transient atrial dysfunction occurred in some. The most important factor influencing immediate recovery of atrial function is duration of atrial fibrillation (6). Atrial function is normal after brief periods of atrial fibrillation, but is reduced or absent when conversion is achieved after the arrhythmia has sustained >1 week. Cox et al. (17) found Doppler examination to be the most accurate in evaluating the presence or absence of atrial mechanical function postoperatively. In this study, left atrial paralysis occurred in 11 (73%) of 15 patients at 1 week and in 6 (43%) of 14 at 2 months after operation. Right atrial paralysis occurred in 9 (60%) of 15 patients at 1 week and in 1 (7%) of 14 at 2 months after operation. Both left and right atrial mechanical function recovered at 6 months in 14 patients after operation. Prolonged absence of atrial mechanical function in these patients possibly occurred because of the chronic nature of atrial fibrillation and the underlying etiology of mitral valve disease. More than half of our patients had rheumatic heart disease. Nonvalvular atrial fibrillation was the most common etiology in the study using electrical cardioversion to stop atrial fibrillation.

The mechanism of atrial dysfunction after elimination of atrial fibrillation is unknown. Shapiro et al. (6) postulated that postischemic stunned atrial myocardium, as in the occurrence of ischemia during fibrillation of the ventricles (18,19), may explain this phenomenon. This study found that the mechanical function of the right atrium recovered earlier than that of the left. These findings have not been reported previously. Rheumatic heart disease is a chronic inflammatory process that causes fibrotic changes in the atrium. The inflammatory process causes more fibrotic change in the left than the right atrium and may cause more ischemia in the left atrium. Thus, functional recovery of the left atrium is slower.
Comparison with previous studies. The success rate of surgical cardioversion by atrial compartment operation is comparable to that of electrical cardioversion (20,21), although it is difficult to compare the success of electrical cardioversion and surgical treatment because of the different characteristics of the patients.

Several surgical methods for atrial fibrillation have been developed in the past. The long-term result in the study of Graffigna et al. (10) showed persistence of sinus rhythm in 72% of patients who underwent left atrial isolation with mitral valve surgery. However, these investigators did not show whether atrial function recovered after left atrial isolation. The left atrial isolation procedure (22) does not reduce the patient’s risk of thromboembolism because the left atrium may continue to fibrillate.

The “corridor operation” is another method for the surgical cure of atrial fibrillation (13). Theoretically, fibrillatory impulses are separated from sinus impulses after this operation, and atrial fibrillation no longer influences ventricular rate. In this method, a major portion of the atrium excluded from access to sinus impulses remains fibrillary or silent and provides no synchronous atrial contraction. Therefore, atrial kick is lost, and cardiac hemodynamic function is not restored to normal.

The “maze operation” is the third new method for the surgical cure of atrial fibrillation. This method has proved to be effective in both converting to sinus rhythm and regaining atrial contractility (9,17). However, the maze operation is meticulous and time-consuming and takes more cardiac ischemic time, especially when other cardiac procedures are performed simultaneously. Compartment operation provides a more simple method and imposes less stress on the patient.

Study limitations. The patients in this study were selected, especially those who were willing to undergo the compartment operation and those for whom the duration of ischemic time for concomitant cardiac procedure was expected to be <60 min. The compartment operation should be cautiously added to any valvular surgery when the duration of ischemic time is expected to be longer. Only relatively small patient groups were investigated in this study, leading to diminished sensitivity of the clinical characteristics studied. Ideal subjects who are likely to resume sinus rhythm after operation and would derive the greatest benefit by avoiding the detrimental effects of chronic atrial fibrillation and by assuming the least risk from the additional operation were not used in this study. In addition, Doppler E and A wave measurements do not measure atrial function directly. Changes in ventricular diastolic function can influence these measurements (23). Therefore, the differences between left and right atrial function measurements could potentially reflect changes in the time course of recovery of left and right ventricular systolic and diastolic function after surgery. Left atrial appendage function is difficult to study using transthoracic echocardiography because it does not always parallel function of the rest of the left atrium, and even patients in sinus rhythm may develop left atrial appendage thrombus (24).

Clinical implications. Simultaneous surgical correction of mitral valve lesions and chronic atrial fibrillation can be done safely. Prolonged atrial dysfunction occurs after surgical cardioversion of atrial fibrillation. Atrial paralysis leads to stagnation of atrial blood flow and subsequently to an increased risk of thromboembolism. Anticoagulant therapy should be continued for a period. Doppler echocardiography may be used to guide the recovery of atrial contractile function.

Conclusions. Chronic atrial fibrillation in mitral valve disease can often be eliminated by atrial compartment operation during mitral valve surgery. Prolonged absence of bilateral atrial mechanical function detected by Doppler study occurs in most patients after operation. Both left and right atrial mechanical function recover after atrial compartment operation, and in fact improve over time.

References