Ten-Year Experience of Chordal Replacement With Expanded Polytetrafluoroethylene in Mitral Valve Repair

Junjiro Kobayashi, MD; Yoshikado Sasaki, MD; Ko Bando, MD; Kenji Minatoya, MD; Kazuo Niwaya, MD; Soichiro Kitamura, MD

Background—Mitral valve repair is the procedure of choice to correct mitral regurgitation (MR). Although chordal replacement with expanded polytetrafluoroethylene (ePTFE) has been widely accepted to repair anterior mitral prolapse and other difficult situations, the long-term results of the repair and the fate of ePTFE have not been delineated.

Methods and Results—From July 1988 to April 1999, 74 patients (49 males, 25 females) aged 17 to 77 years (mean age 55.3±14.8 years) underwent mitral valve repair with chordal replacement with ePTFE. The follow-up period was from 6 months to 11.3 years (mean 4.6±3.2 years). The causes of MR were degenerative in 65 patients (88%) and infective in 9 (12%). Three patients had active infective endocarditis. Valve lesions were anterior in 35 patients, posterior in 10, and both anterior and posterior in 29. Various procedures for plasty of leaflets were necessary in 37 patients (50%). Atrial fibrillation was associated in 38 patients (51%), and the maze procedure has been performed in a selected group of 30 patients (41%) since July 1992. There was 1 in-hospital death (1.4%) and 3 late cardiac deaths (4.1%). More than moderate MR developed in 12 patients (17%) during the follow-up period. Three of these patients required early reoperation within 1 year due to hemolysis. Two patients underwent mitral valve replacement at 6 and 8 years after repair, respectively. The actuarial reoperation-free rates at 5 and 10 years were 94.3±2.8% and 81.7±9.1%, respectively. Sinus rhythm was restored in 21 patients (70%) with the maze procedure. There was only 1 thromboembolic episode (0.3%/patient-y) in a patient with atrial fibrillation who did not undergo the maze procedure. Event-free survival rates as assessed by the freedom from cardiac death, thromboembolism, reoperation, and anticoagulation-related hemorrhage at 5 and 10 years were 91.3±3.4% and 71.6±9.7%, respectively. There was no relationship between recurrent MR and the change of ePTFE. Structural analysis of the ePTFE resected during reoperation revealed no calcification and showed remaining flexibility and pliability. Protein infiltration was observed in the ePTFE, and collagenous proliferation was recognized at the site of fixation to the valve leaflet and the papillary muscle. The surface of the ePTFE was completely endothelialized, which may induce antithrombogenicity.

Conclusions—The long-term durability and biological adaptation of ePTFE as artificial chordae for mitral valve repair of MR were proved for >10 years. (Circulation. 2000;102[suppl III]:III-30-III-34.)

Key Words: mitral valve ▪ arrhythmia ▪ surgery

Mitral valve repair is the procedure of choice to correct mitral regurgitation (MR), and results superior to those from mitral valve replacement have been reported.1-2 Prolapse of the posterior leaflet can be treated with quadrangular resection of the prolapsing segment.3 The correction of anterior leaflet prolapse is more difficult than the correction of the posterior leaflet prolapse. Triangular resection, chordal shortening, and chordal transfer have been reported to repair anterior leaflet prolapse.3-5 However, it is sometimes difficult to repair complicated lesions with only these techniques. Although chordal replacement with expanded polytetrafluoroethylene (ePTFE) has been introduced to repair anterior mitral prolapse and other difficult situations,6-7 long-term results of the repair and the fate of ePTFE have not been fully delineated. In the present study, we report >10 years of experience with chordal replacement with ePTFE.

Methods

Patients

Between July 1988 and April 1999, 218 patients underwent mitral valve repair for MR in our institution. In 74 patients, mitral valve repair was performed with chordal replacement with ePTFE. The patient group consisted of 49 males and 25 females, and their age at surgery ranged from 17 to 77 years (mean±SD age at surgery 55.3±14.8 years). Primary valve disease was degenerative in 65 (88%) and infective in 9 (12%). Three patients had active infective endocarditis. MR associated with atrial septal defect, ischemia, or cardiomyopathy was excluded. Table 1 summarizes the clinical profile of the patients. Most of the patients were in New York Heart Association (NYHA) functional class III or IV. Preoperative left ventricular end-systolic diameter was within normal range or slightly enlarged in most of the patients. Atrial fibrillation (AF) was associated with 38 patients (51%).

From the Department of Cardiovascular Surgery, National Cardiovascular Center, Osaka, Japan.
Correspondence to Junjiro Kobayashi, MD, Department of Cardiovascular Surgery, National Cardiovascular Center, 5-7-1 Fujishiro-dai, Suita-City, Osaka 565-8565, Japan. E-mail jkobayas@hsp.ncvc.go.jp
© 2000 American Heart Association, Inc.
Circulation is available at http://www.circulationaha.org

III-30
Surgical Findings
Intraoperative analysis revealed that MR was caused by the prolapse of the anterior leaflet in 35 patients (47%), diffuse posterior leaflet in 10 (14%), and both anterior and posterior leaflets in 29 patients (39%). Vegetation was found in 3 patients (4%) with active infective endocarditis. Annular dilatation was noted in every patient.

Surgical Procedures
Table 2 summarizes the surgical techniques used in the present series. The method of artificial chordal replacement was described previously. Recently, the technique was slightly modified for several reasons. The 5-0 double-armed ePTFE suture with a small Teflon pledget was passed through the papillary muscle from base to attachment of the chordae. Each end of the suture was passed through the prolapsed leaflet separately from the left ventricle to the left atrium and passed again from ventricle to atrium and then tied on the left atrial side (Figure 1). The length of the artificial chordae was adjusted with the adjacent normal anterior leaflet or facing posterior leaflet. The number of replaced artificial chordae ranged from 2 to 12 (mean ± SD 6.0 ± 2.2).

Associated procedures for the mitral leaflet were quadrangular resection of the posterior leaflet (n = 25, 34%), edge-to-edge repair at the paracommissural site (n = 5, 7%), vegetectomy (n = 3, 4%), and closure of perforation (n = 1, nearly 1%). Wedge resection, plication, or other procedures were applied in 9 patients (12%). Multiple procedures in addition to chordal replacement were necessary in 37 patients (50%). Annuloplasty was performed in all patients. Kay’s suture annuloplasty was used in 50 patients (65%), and ring annuloplasty was used in 41 (55%).

Simultaneous procedures included the maze procedure (n = 30, 41%), tricuspid annuloplasty (n = 17, 23%), aortic valve repair (n = 1, nearly 1%), and CABG (n = 1, nearly 1%). Regarding the maze procedure, we performed Kosakai’s modified maze procedure in 26 patients and the modified Cox maze III procedure in 4. The cardiopulmonary bypass and aortic cross-clamp times were 179 ± 48 and 126 ± 32 minutes, respectively.

Echocardiographic Study
Transseptal echocardiography with pulsed Doppler study was performed before and after the operation. The motion and the thickening of the ePTFE were evaluated. MR was estimated with color Doppler according to the ratio of regurgitant jet area to left atrial area (trivial < 5%, mild < 20%, moderate 20% to 40%, severe > 40%).

Data Collection
The status of patients was determined by referring to the medical records and correspondence with the responsible physicians. All of the cardiac and noncardiac events were recorded in detail. Patients were followed up with ECG and echocardiography with pulsed Doppler study every 3 to 12 months. We defined the sinus rhythm if the P wave was present. The presence of the A wave through the mitral and tricuspid valves on pulsed Doppler study was determined with independent analysis by the cardiologists. The follow-up period after surgery ranged from 6 months to 11.3 years (mean ± SD 4.6 ± 3.2 years). Patients with AF received anticoagulation therapy.

<table>
<thead>
<tr>
<th>TABLE 1. Preoperative Patient Characteristics</th>
</tr>
</thead>
<tbody>
<tr>
<td>Age, mean y (range) 55.3 ± 14.8 (17–77)</td>
</tr>
<tr>
<td>Sex, M/F 49/25</td>
</tr>
<tr>
<td>NYHA functional class II/III/IV, n 2/68/4</td>
</tr>
<tr>
<td>Degree of MR, n (%)</td>
</tr>
<tr>
<td>Grade 3/4 8 (11)</td>
</tr>
<tr>
<td>Grade 4/4 66 (89)</td>
</tr>
<tr>
<td>LVESD, n (%)</td>
</tr>
<tr>
<td>&lt;45 mm 54 (73)</td>
</tr>
<tr>
<td>45–50 mm 17 (23)</td>
</tr>
<tr>
<td>&gt;50 mm 3 (4)</td>
</tr>
<tr>
<td>AF, n (%) 38 (51)</td>
</tr>
<tr>
<td>Associated disease, n (%)</td>
</tr>
<tr>
<td>Tricuspid regurgitation 17 (23)</td>
</tr>
<tr>
<td>Aortic regurgitation 1 (1)</td>
</tr>
<tr>
<td>Coronary artery disease 1 (1)</td>
</tr>
<tr>
<td>LVESD indicates left ventricular end-systolic diameter on echocardiography.</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>TABLE 2. Surgical Procedures Performed</th>
</tr>
</thead>
<tbody>
<tr>
<td>Procedure n (%)</td>
</tr>
<tr>
<td>Procedures for leaflets</td>
</tr>
<tr>
<td>Chordal replacement 74 (100)</td>
</tr>
<tr>
<td>No. of chordae</td>
</tr>
<tr>
<td>2 26 (35)</td>
</tr>
<tr>
<td>4 32 (43)</td>
</tr>
<tr>
<td>6 10 (14)</td>
</tr>
<tr>
<td>8–12 6 (8)</td>
</tr>
<tr>
<td>Quadrangular resection 25 (34)</td>
</tr>
<tr>
<td>Closure of perforation 1 (1)</td>
</tr>
<tr>
<td>Vegetectomy 3 (4)</td>
</tr>
<tr>
<td>Edge-to-edge repair 5 (7)</td>
</tr>
<tr>
<td>Others 9 (12)</td>
</tr>
<tr>
<td>Annuloplasty 74 (100)</td>
</tr>
<tr>
<td>Kay method 50 (68)</td>
</tr>
<tr>
<td>Ring annuloplasty 41 (55)</td>
</tr>
<tr>
<td>Concomitant procedure</td>
</tr>
<tr>
<td>Maze procedure 30 (41)</td>
</tr>
<tr>
<td>Tricuspid annuloplasty 17 (23)</td>
</tr>
<tr>
<td>Aortic valvuloplasty 1 (1)</td>
</tr>
<tr>
<td>CABG 1 (1)</td>
</tr>
</tbody>
</table>

Figure 1. Illustration of chordal replacement with ePTFE suture. A double-armed 5-0 ePTFE suture with small Teflon pledget is passed through papillary muscle from base to attachment of chordae. Each end of suture is passed through the prolapsed leaflet separately from the left ventricle to the left atrium and passed again from ventricle to atrium and tied on the left atrial side.
Statistical Analysis
All values are expressed as mean ± SD. Actuarial curves were computed with the Kaplan-Meier method.

Results
There was only 1 hospital death, which occurred in a 22-year-old woman with Marfan’s syndrome. She was admitted with preshock and anuria and underwent emergency mitral valve repair. We performed 12-suture ePTFE chordal reconstruction for the anterior and posterior leaflet prolapse and annuloplasty with Kay’s method. The patient died of low cardiac output syndrome.

Table 3 lists the early and late complications. Perioperative myocardial infarction occurred in 2 patients. One patient had anteroseptal myocardial infarction due to occlusion of the left anterior descending coronary artery distal to the anastomosed site with the left internal thoracic artery. The other patient had posterolateral myocardial infarction without an occluded coronary artery branch on postoperative coronary angiography. The chest was reopened due to bleeding in 2 patients. Hemolysis with moderate MR was found in an 18-year-old woman who had active infective endocarditis before the operation. She underwent mitral valve replacement with a biological valve 1 week after mitral valve repair. There was 1 cerebral complication without any neurological deficit.

**Patient Survival**
There have been 4 late deaths. The causes of death were sudden death (n = 2), congestive heart failure (n = 1), and gastric cancer (n = 1). The actuarial survival rates at 5 and 10 years were 96.9 ± 2.2% and 89.3 ± 5.6%, respectively (Figure 2).

**Recurrence MR and Reoperation**
The grade of MR immediately after surgery was none to mild in 71 patients (97%) (Table 4). Twelve patients (17%) had recurrent MR (color Doppler grade moderate to severe) in the late follow-up period. Five of these patients (7%) required reoperation. Three were reoperated on within 1 year, and the other 2 were reoperated on 6 and 8 years after the initial surgery. These 2 patients did not have ring annuloplasty. The indication for reoperation was congestive heart failure (n = 4) and hemolysis (n = 1). Breakage of the replaced ePTFE chordae or tearing of the leaflet or papillary muscle at the attachment of ePTFE chordae did not occur in patients with recurrent MR. The actuarial reoperation-free rates at 5 and 10 years were 94.3 ± 2.8% and 81.7 ± 9.1%, respectively (Figure 3).
was observed in only 2 patients (3%), whose mitral valve orifice was restricted movement of the mitral leaflet was Thickening and stiffening of ePTFE were observed with time. 3.4% and 71.6% of mitral leaflet movement. Significant thickening and stiffening of ePTFE were observed in patients with ring annuloplasty. However, correction of the prolapse of anterior mitral leaflet remains a challenging procedure. Although we had applied chordal shortening in the early series, re-elongation or rupture of the shortened chordae in the follow-up period was occasionally experienced that caused recurrent MR. Similar disappointing results were reported at some institutions.

Thromboembolic Complication
There was only 1 stroke, which occurred 7 years after the surgery (0.3%/patient-y). This patient had been followed up without anticoagulation despite the development of AF.

Cardiac Rhythm
Sinus rhythm was regained in 21 of the patients (70%) who underwent the maze procedure. However, AF developed in 2 patients who were in sinus rhythm before the operation. Therefore, 54 patients (74%) maintained sinus rhythm in the follow-up. Three patients underwent pacemaker implantation for sick sinus syndrome although AF returned to sinus rhythm.

Event-Free Survival
Event-free survival rates as assessed as the freedom from cardiac death, thromboembolism, reoperation, and anticoagulation-related hemorrhage at 5 and 10 years were 91.3 ± 3.4% and 71.6 ± 9.7%, respectively (Figure 5.).

Postoperative Echocardiography
Thickening and stiffening of ePTFE were observed with time. However, restricted movement of the mitral leaflet was observed in only 2 patients (3%), whose mitral valve orifice was <1.5 cm². Of these patients, 1 patient had 8 ePTFE 4-0 sutures with a No. 26 Carpentier-Edward ring, and the other had 12 ePTFE 4-0 sutures for chordal replacement. In 21 patients who underwent the maze procedure and had restoration of sinus rhythm, transvalvular A wave by the atrial contraction was detected in 15 (71%). There was no left ventricular outflow obstruction on pulsed Doppler study.

Discussion
Mitral valve repair has gained increasing popularity due to the variety of techniques available for the repair of various mitral valve lesions. The repair of posterior leaflet prolapse was established with simple quadrangular resection with ring annuloplasty. However, correction of the prolapse of anterior mitral leaflet remains a challenging procedure. Plication or resection of the anterior leaflet was reported to be unfavorable and not applicable to a large area of prolapse. If the cause of mitral prolapse is chordal elongation, chordal shortening is the procedure of choice. Although we had applied chordal shortening in the early series, re-elongation or rupture of the shortened chordae in the follow-up period was occasionally experienced that caused recurrent MR. Similar disappointing results were reported at some institutions.

Chordal transfer was accepted as another technique to resolve the problem of anterior leaflet prolapse. The transfer of secondary chordae to the free margin and of the segment of posterior leaflet facing the prolapsed anterior leaflet was introduced. Although satisfactory results have been obtained with chordal transfer, these procedures are complicated and technically demanding. Chordal replacement of ePTFE is an alternative technique that was initiated after experimental study. In the present study, actuarial rates of freedom from reoperation were 94% at 5 years and 82% at 10 years. David et al reported a rate of freedom from reoperation of 94% at 10 years. Our results were slightly worse than their report probably because the incidence of both anterior and posterior prolapse, AF, and NYHA functional class III or IV was higher in our series. In addition, we had not adapted ring annuloplasty in the early series. Ring annuloplasty changes the mitral valve from a bicuspid valve to a functionally monocuspid valve through the stabilization of the posterior leaflet, which becomes a buttress against which the anterior leaflet can open and close. These results are thought to be very important for the prevention of late structural valve degeneration if mild MR remains. The lack of ring annuloplasty was reported by Cohn et al to be a risk factor of reoperation. Compared with the long-term results of chordal transfer, Smedira et al reported a reoperation-free rate of 96% at 5 years. We believe chordal replacement with ePTFE is as good as chordal transfer.

The causes of recurrent MR and reoperation were not related to the degeneration of implanted ePTFE. However, the thickness and stiffness of ePTFE were increased with time as demonstrated on echocardiography. Mitral valve stenosis developed in 2 patients during the follow-up. In these patients, large numbers of ePTFE chordae and small rings were used. Restrictive motion of the anterior leaflet with inflexible ePTFE chordae induced mitral stenosis, although it was clinically asymptomatic. Extracted ePTFE artificial chordae during reoperation were thicker than the original, with protein infiltration into the inner layer. They were still pliable and not thicker than native chordae. Because of these findings of thickening and stiffening of ePTFE with time, we changed the ePTFE size from 4-0 to 5-0 and made the number of ePTFE chordae as few as possible. If the paracommissural lesion of anterior and posterior prolapse is present, we began

![Figure 4. Left, Pathological findings of extracted ePTFE artificial chordae 6 years after surgery. Protein infiltration is observed in inner layer. Right, Surface of ePTFE is completely endothelialized. Arrow indicates ePTFE suture.](image)

![Figure 5. Actuarial event-free survival curve.](image)
to use the edge-to-edge technique.\textsuperscript{10} MR is frequently the result of several lesions, and multiple techniques are often required for successful repair. Simple technique is very important as a concomitant procedure with ePTFE chordal replacement to shorten the aortic cross-clamp time.

The actuarial event-free rates were 91% at 5 years and 72% at 10 years in our series. There was only 1 thromboembolic episode (0.3%/patient-y) in patients with AF. This result is in keeping with event-free survival rates at 10 years of 75% from David et al\textsuperscript{20} and of 69% from Alvarez et al.\textsuperscript{21} On microscopic examination, the outer surface of ePTFE was completely endothelialized, which may induce antithrombogenicity. David et al\textsuperscript{22} reported that thromboembolism was related to AF and an age at surgery of >60 years, so our excellent result was probably related to the higher incidence of sinus rhythm maintained after the operation with the maze procedure. The preoperative AF rate of 48% was improved to 74% postoperatively in our series. Recently, Wu et al\textsuperscript{25} reported that AF is a significant independent preoperative risk factor for increased long-term mortality rates after surgical correction for myxomatous MR. The maze procedure should be considered as a concomitant procedure with mitral valve repair in selected patients who have a high possibility of the restoration of normal sinus rhythm.\textsuperscript{26}

Regarding the technique of ePTFE chordal replacement, several procedures have been reported.\textsuperscript{6,7} Our procedure became similar to that of Cohn et al.\textsuperscript{27} We adjust the length of ePTFE at the level of the mitral leaflet in the left atrium, which is applicable even in minimally invasive cardiac surgery. The pledge for reinforcement is not tied at the papillary muscle so as not to induce ischemia and abrupt rupture. We have never experienced breakage of the tissue at the level of leaflet or papillary muscle.

In conclusion, chordal replacement with ePTFE sutures is considered to be a reliable procedure, although our study is limited by its retrospective and nonrandomized nature. Long-term durability and biological adaptation of ePTFE as artificial chordae for mitral valve repair despite thicknessening and stiffening with time were proved for >10 years.

References

Ten-Year Experience of Chordal Replacement With Expanded Polytetrafluoroethylene in Mitral Valve Repair
Junjiro Kobayashi, Yoshikado Sasaki, Ko Bando, Kenji Minatoya, Kazuo Niwaya and Soichiro Kitamura

*Circulation.* 2000;102:III-30-III-34
doi: 10.1161/01.CIR.102.suppl_3.III-30
*Circulation* is published by the American Heart Association, 7272 Greenville Avenue, Dallas, TX 75231
Copyright © 2000 American Heart Association, Inc. All rights reserved.
Print ISSN: 0009-7322. Online ISSN: 1524-4539

The online version of this article, along with updated information and services, is located on the World Wide Web at:
http://circ.ahajournals.org/content/102/suppl_3/III-30

Permissions: Requests for permissions to reproduce figures, tables, or portions of articles originally published in *Circulation* can be obtained via RightsLink, a service of the Copyright Clearance Center, not the Editorial Office. Once the online version of the published article for which permission is being requested is located, click Request Permissions in the middle column of the Web page under Services. Further information about this process is available in the Permissions and Rights Question and Answer document.

Reprints: Information about reprints can be found online at:
http://www.lww.com/reprints

Subscriptions: Information about subscribing to *Circulation* is online at:
http://circ.ahajournals.org/subscriptions/