A 20-year experience with mitral valve repair with artificial chordae in 608 patients

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Supplemental material is available online.

Objective: Mitral valve repair with artificial chordae for degenerative mitral regurgitation is widely adopted. We evaluated long-term results of mitral repair with expanded polytetrafluoroethylene sutures (GORE-TEX CV-5; W. L. Gore & Associates, Inc, Flagstaff, Ariz).

Methods: Between November 1986 and November 2006, 608 consecutive patients underwent mitral repair with artificial neochordae. Mean age was 55 ± 11 years (15–85 years); 433 (71.2%) were male. Valve disease was purely degenerative in 555 patients (91.3%). Prolapse of anterior, posterior, or both leaflets was present in 47 (7.7%), 308 (50.7%), and 253 (41.6%), respectively. Atrial fibrillation was associated in 117 (19.2%). In 125 cases (20.5%), additional surgical procedures were performed. Follow-up was complete at a median of 5.7 years (interquartile range 2.2–9.8 years, range 0–19.4 years).

Results: In-hospital mortality was less than 1% (6 deaths). Overall and cardiac late mortalities were 6.6% and 3.9% (34 and 24 deaths). Kaplan–Meier survival at 15 years was 84% (95% confidence interval 75%–90%). Freedoms from endocarditis, thromboembolic events, reoperation, and recurrent mitral regurgitation at 15 years were 97% (95% confidence interval 93%–99%), 92% (87%–95%), 92% (88%–95%), and 85% (78%–91%), respectively. Sinus rhythm was restored in 75% (33 patients) after surgical atrial fibrillation correction. Calcification of GORE-TEX neochordae was never reported.

Conclusion: Mitral valve repair with GORE-TEX artificial chordae is effective, safe, and associated with low operative mortality and low rates of valve-related complications at long-term follow-up. Artificial chordae showed excellent biologic adaptation, retaining flexibility and tension with time.

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Mitral valve (MV) repair has become the procedure of choice for the treatment of mitral regurgitation (MR), with superior results relative to MV replacement.^{1,2} MV repair is feasible in as many as 95% of cases of degenerative MV regurgitation,³ despite the presence of complex lesions. The Carpentier quadrangular resection, with or without concomitant sliding plasty, is considered the standard surgical technique to correct posterior leaflet prolapse.⁴ Various types of reconstructive procedures, including triangular resection, chordal transfer, chordal shortening, edge-to-edge technique, and papillary muscle repositioning, have been used to repair anterior leaflet prolapse. MV repairs with these techniques are not always satisfactory, and some of these procedures are considered technically demanding.^{4–6}

Chordal replacement with expanded polytetrafluoroethylene (ePTFE) sutures (GORE-TEX sutures; W.L. Gore & Associates, Inc, Flagstaff, Ariz) was introduced experimentally by Frater and colleagues⁷ in the early 1980s. Current use in clinical practice has permitted repair of complex mitral lesions with a now widely adopted technique.^{3,8,9}

Abbreviations and Acronyms

AF	= atrial fibrillation
CI	= confidence interval
ePTFE	= expanded polytetrafluoroethylene
IQR	= interquartile range
MR	= mitral regurgitation
MV	= mitral valve
SAM	= systolic anterior motion

In this study, we report 20 years of experience of MV repair with ePTFE suture in 608 consecutive patients. To our knowledge, this is the largest reported series and the longest follow-up study of this technique.

Patients and Methods

From 1986 to 2006, a total of 608 consecutive patients with severe MR underwent MV repair with artificial neochordal implantation at our institution. There were 433 men (71.2%) and 175 women. Ages ranged from 15 to 85 years (mean 55.5 ± 11.5 years). Table 1 shows patients' clinical profiles and the prolapsing leaflets. In cases of mild ascending aorta dilation (5 patients) and absence of significant aortic valve disease (3 patients), there was no concomitant surgical indication. The cause of valve disease was purely degenerative in 555 patients (91.3%). Fifty-three patients (8.7%) had degenerative MR complicated by infective endocarditis. Atrial fibrillation (AF) was present in 117 patients (19.3%). Coronary angiography was performed in patients older than 50 years and in those with suspected coronary artery disease.

Operative Procedures

The approach to the heart was exclusively by means of a midsternotomy until April 2006; since then, most of the operations have been performed with a videoendoscopic port-access approach through a right minithoracotomy. MV repair was performed with cardiopulmonary bypass under moderate hypothermia. Myocardial protection was achieved by both intermittent cold blood cardioplegia and topical cooling for midsternotomy, whereas in minimally invasive surgery cold crystalloid solution Custodiol (Koehler Chemie, Alsbach-Haenlien, Germany) was infused. The MV was approached through a standard left atriotomy with an incision made just behind the interatrial groove. The entire MV apparatus was then carefully inspected, and prolapse of the leaflets was identified by examining the level of the free margin of each portion of the leaflets. Resection of the posterior leaflet according to the Carpentier technique⁴ was performed in 351 patients (57.7%). Indications for GORE-TEX chordoplasty, in combination with posterior leaflet resection, were mainly as follows: (1) bileaflet prolapse (posterior resection plus neochordae on anterior mitral leaflet); (2) need for a small posterior mitral leaflet tissue resection to provide a better coaptation against anterior mitral leaflet, with neochordal implantation mandatory in this case to ensure a more stable connection between leaflet and papillary muscles; and (3) Barlow disease, where reconstruction after extensive posterior leaflet resection can leave an area without native chordal support. Such technique was used less frequently in the last few years. Actually, we prefer to resect only posterior mitral leaflet tissue excess parallel to the margin. This means to resect an adequate

TABLE 1. Clinical characteristics of patients with severe mitral regurgitation

No. of patients	608
Age (y, mean $\pm$ SD)	55.5 ± 11.5
Male (No.)	433 (71.2%)
Electrocardiography (No.)	
Sinus rhythm	491 (80.7%)
Atrial fibrillation	117 (19.3%)
Mitral valve pathology (No.)	
Pure degenerative	555 (91.3%)
Degenerative plus endocarditis	53 (8.7%)
Prolapsing leaflet (No.)	
Anterior	47 (7.7%)
Posterior	308 (50.7%)
Bileaflet	253 (41.6%)
New York Heart Association functional class (No.)	
I	155 (26.7%)
II	270 (46.6%)
III	134 (23.1%)
IV	21 (3.6%)
Associated disease (No.)	
Total cases	125 (20.5%)
Coronary artery disease	24 (3.9%)
Atrial septal defect or patent foramen ovale	43 (7.1%)
Aortic valve disease	14 (2.3%)
Tricuspid valve regurgitation	13 (2.1%)
Dilatation of ascending aorta	8 (1.3%)
Previous cardiac surgery (No.)	3 (0.5%)
Left ventricular ejection fraction <40%	47 (7.7%)

segment of prolapsing tissue close to the free margin, to align P2 height with P1 height, when this scallop appears of normal size; however, it creates a reduction that leaves about 1.5 cm height from the annulus. Where ruptured or elongated chordae were attached and resected, we replaced with ePTFE sutures.

Prolapse of the anterior leaflet was managed by chordal replacement with ePTFE sutures only. Other techniques, such as triangular resection, chordal transfer, or chordal shortening, have never been used at our institution. We described the technique of chordal replacement with ePTFE suture in a previous publication.¹⁰ Briefly, we use an ePTFE double-armed suture (GORE-TEX CV-5) that is passed through the papillary muscle with a mattress technique and is reinforced with autologous pericardial pledgets (or, rarely, with GORE-TEX pledgets) on both sides of the muscle. Each end of the suture is then fixed to the free margin of the prolapsed leaflet and is reinforced with a small autologous pericardial pledget (or, less frequently, a small GORE-TEX pledget). The length of the artificial chordae is adjusted to maintain the corresponding free margin of the leaflets at the desired level in the ventricular cavity. To determine the correct length of the artificial chordae so that an adequate coaptation area is obtained and any significant prolapse is reduced, the neochordae are tied at the end of all the other repair procedures after the ventricular cavity is filled with saline solution.

In 48 selected cases (7.9%), after the leaflet repair was accomplished, if thin or fragile natural chordae tendineae were identified, even if not elongated or ruptured, a couple of artificial chordae were implanted as a protective function ("sentinel" neochordae) to

prevent the effects of disease progression. None of the patients received only sentinel neochordae. These were placed as an extra support to ensure a better stability. According to Cox regression analysis, no difference was found in terms of durability of the repair, presence of significant MR, or mortality. Their precise role and, eventually, possible protective factor should be the subject of a deeper analysis of a larger series of patients. Most patients (99%) underwent posterior annuloplasty. An autologous pericardial band¹¹ was used in 487 patients (80.1%), and rigid or flexible artificial rings were used in 116 patients (19.1%). The choice between pericardium or prosthetic ring is determined by the surgeon's preference, anatomy, quality of pericardium, and age of the patient. Implantation of a prosthetic ring is related to advanced age. We adopted a quite simple method involving the Carpentier sizers and the patient's body surface area. We assume that a body surface area smaller than 160 m² would need Carpentier size number 32; we therefore cut the pericardial band around the sizer. Between 1.60 and 1.80 m², a 34 size was used, and above 1.80 m², we used the 36. In 5 cases we did not perform a pericardial or prosthetic ring annuloplasty: 3 patients underwent simple suture annuloplasty, and 2 had the annulus stabilized by calcification or fibrosis. Since the year 2000, a surgical procedure for AF has been performed with radiofrequency or microwave energy in 44 selected patients with AF at hospital admission. Among these, 18 (41%) had permanent AF; the remaining 26 (59%) had persistent AF. Another 12 radiofrequency ablations were performed for cases of paroxysmal AF but were excluded from the count because patients had sinus rhythm at admission.

In all cases, warfarin sodium for anticoagulation was administered during the first 3 months after surgery and was discontinued if sinus rhythm was established. Table 2 summarizes operative data.

Follow-up

Demographic, morphologic, echocardiographic, and surgical data were obtained from hospital records. Patients were followed up at annual intervals with telephone interviews and echocardiographic studies. The median follow-up was 5.2 years (interquartile range [IQR] 1.8–9.0 years). Complete follow-up information was available for 602 survivors of the initial hospital stay (100%). The median follow-up was 5.7 years (IQR 2.2–9.8 years, range 0–19.4 years).

Statistical Analysis

STATA software (version 9.2; StataCorp LP, College Station, Tex) was used for all statistical analyses. Continuous values are expressed as mean $\pm$ SD or median and IQR. Comparisons between groups were made with analysis of variance for continuous variables and χ^2 test or Fisher exact test as appropriate for categorical variables. Late survivals and freedoms from adverse events were estimated with the nonparametric Kaplan–Meier method. Cox regression analysis with backward selection was used to identify the multivariable and independent predictors of late outcomes. Variable retention in the models was set at a *P* value of .05.

Results

Operative and Late Mortalities

There were 6 perioperative deaths (<1%), all related to low cardiac output syndrome (Table 3). In 3 of these cases, the MV was replaced for residual severe regurgitation (1 as a

TABLE 2. Operative data

Operations performed	
Chordal replacement with e-PTFE	608 (100%)
Chordae replaced (No., mean and range)	6 (4–8)
Anterior chordal replacement	325 (53.5%)
Posterior chordal replacement	544 (89.5%)
Sentinel neochordae	
Procedures	48 (7.9%)
No. placed (mean and range)	3 (2–6)
Resection of posterior leaflet	351 (57.7%)
Mitral annuloplasty	606 (99.7%)
None	2 (0.3%)
Suture annuloplasty	3 (0.5%)
Pericardial ring	487 (80.1%)
Artificial ring	116 (19.1%)
Additional procedures	214 (35.2%)
Atrial fibrillation surgical treatment	44 (7.2%)
Tricuspid valve repair	13 (2.1%)
Coronary artery bypass grafting	24 (3.9%)
Aortic valve replacement	6 (1%)
Aortic valve repair	5 (0.8%)
Repair of congenital atrioseptal defect	43 (7.1%)
Left atrial appendage closure	146 (24%)
Ascending aorta replacement	3 (0.5%)
Cardiopulmonary bypass time (min, mean $\pm$ SD)	135.2 $\pm$ 34.5
Crossclamp time (min, mean $\pm$ SD)	109.1 $\pm$ 31.3

All values are numbers (and percentages) of patients unless otherwise specified. ePTFE, Expanded polytetrafluoroethylene.

result of medically intractable systolic anterior motion [SAM]). Thirty-four deaths occurred during follow-up (24 cardiac-related deaths and 10 non-cardiac-related deaths). The causes of cardiac-related death were heart failure (*n* = 10), sudden cardiac death (*n* = 9), myocardial infarction (*n* = 3), and stroke (*n* = 2). Cumulative survival at 15 years was 84% (95% confidence interval [CI] 75%–90%; Figure 1).

TABLE 3. In-hospital morbidity and mortality

In-hospital mortality	6 (1.0%)
Perioperative morbidity	94 (15.5%)
Myocardial infarction	1 (1.1%)
Low cardiac output syndrome requiring IABP, with or without VAD	5 (5.3%)
Heart failure	24 (25.6%)
Renal failure	9 (9.6%)
Respiratory insufficiency	13 (13.8%)
Stroke and transient ischemic attack	10 (10.6%)
Postoperative bleeding necessitating surgical exploration	32 (34%)
Mitral regurgitation	
>2+	2 (0.3%)
2+	10 (1.6%)

All values are numbers (and percentages) of patients. IABP, intra-aortic balloon pump; VAD, ventricular assist device.

Figure 1. Long-term survival of patients with mitral valve repair with GORE-TEX CV-5 expanded polytetrafluoroethylene suture.

Figure 2. Freedom from reoperation for all patients.

Table 4 shows the independent preoperative and perioperative predictors of late death.

Perioperative Morbidity

Perioperative complications occurred in 94 patients (15.5%) and are listed in Table 3. Three cases of significant SAM,

requiring a second pump run, were successfully treated with the Alfieri edge-to-edge technique,⁵ whereas the other 3 cases were treated with volume adjustment and pharmacologic therapy. Causes of SAM were undersized ring associated with quadrangular resection in 2 cases and ineffective reduction of posterior mitral leaflet length in Barlow disease in 4 cases.

TABLE 4. Cox regression analysis

Outcome	Hazard ratio	95% Confidence interval	P value
Late mortality (n = 34)			
Age, 5-y increase	1.35	1.12–1.62	.002
Segmental resection of posterior leaflet	0.45	0.22–0.92	.028
Associated CABG	2.85	1.66–15.24	.004
Perioperative stroke	8.90	1.81–43.77	.007
Perioperative myocardial infarction	4.96	1.42–17.28	.012
Perioperative respiratory insufficiency	5.39	1.52–19.13	.009
Cardiac-related mortality (n = 24)			
Associated CABG	12.25	3.07–48.8	<.001
Perioperative respiratory insufficiency	9.17	2.76–30.50	<.001
Reoperation on mitral valve (n = 25)			
Age, 5-y increase	1.21	1.01–1.44	.042
Perioperative MR >2	12.97	3.58–44.82	<.001
Moderate to severe MR (n = 35)			
Perioperative MR >2	12.57	4.14–38.14	<.001
Segmental resection of posterior leaflet	0.39	0.19–0.81	.012
Thromboembolic cerebral event (n = 21)			
Perioperative stroke	9.67	1.21–77.15	.032

CABG, Coronary artery bypass grafting; MR, mitral regurgitation.

Reoperation

Twenty-five reoperations (4.1%) were performed during the follow-up period, 3 for MV infective endocarditis and the remainder for progression of the degenerative disease. Overall freedom from MV reoperation was 92% at 15 years (95% CI 88%–95%; Figure 2). No repair failures arising from spontaneous malfunction of GORE-TEX chordae were reported in our series. Cox regression analysis showed that anterior leaflet prolapse was not an independent risk factor for reoperation, recurrent MR, or mortality.

Infective Endocarditis

There were 7 cases (1.1%) of infective endocarditis; 3 patients underwent surgical treatment (2 replacements and 1 re-repair) and 4 were treated with antibiotic therapy. All patients survived. In 1 case, a pair of artificial chordae were involved in a large destruction of the corresponding posterior leaflet and appeared ruptured. Freedom from endocarditis at 15 years was 97% (95% CI 93%–99%) for all patients.

Thromboembolic Events and Anticoagulation-Related Hemorrhage

Thromboembolic complications (transient ischemic attack and stroke) were documented in 21 patients (3.5%). Four patients (19%) had AF. Freedom from thromboembolism at 15 years was 92% (95% CI 87%–95%) for all patients. Since 1999, we have prophylactically closed the left atrial appendage by direct suture in all patients, regardless of

Figure 3. Freedom from recurrent moderate to severe mitral regurgitation for all patients.

sinus rhythm or left atrial dimensions. There were 9 major bleeding episodes among patients who were receiving anticoagulation therapy. The freedom from major bleeding at 15 years was 96.5% (95% CI 87.6%–98.3%) for all patients.

Recurrent MR

A grade of MR more than mild to moderate ($\geq 2+$) immediately after surgery was found in 12 patients (2%; Table 3). Only 2 patients had greater than 2+ MR on leaving the operating room, a result of the lack of transesophageal echocardiography; they were reoperated on a few days later. At the beginning of our experience, we accepted even suboptimal repair, considering that in some patients a second run of cardiopulmonary bypass would be more life-threatening than a 2+ MR. Among these patients, only 3 underwent reoperation, and 1 died of sudden cardiac death. At follow-up, significant MR (more than moderate) was found in 35 patients (5.8%), and 25 underwent reoperation. Overall freedom from significant MR at 15 years was 85% (95% CI 78%–91%; Figure 3). Cox regression analysis identified the presence of more than mild MR at discharge as an independent risk factor for significant recurrent MR at follow-up (hazard ratio 12.57, 95% CI 4.14–38.14; Table 4; Appendix E1).

Atrial Fibrillation

At follow-up, 76 patients (12.5%) had permanent AF. Since 2000, a surgical procedure for AF treatment has been performed in 44 selected patients (7.2%). At follow-up, sinus rhythm was restored in 33 patients (75%). New onset of AF was seen in 40 patients (8.2% of 486) who were recorded as having sinus rhythm before surgery.

Functional Status

Of 543 patients alive and free from reoperation at follow-up, 80.8% were in New York Heart Association functional class I, 17.2% were in New York Heart Association functional

class II, and 2.1% were in New York Heart Association functional class III.

Discussion

MR caused by degenerative disease has been extensively treated with valve repair, which has been shown to be superior to valve replacement in terms of operative mortality, quality of life, and long-term survival. Symptom-free patients also benefit from repair, with their survival after operation found to be identical to that of general population.¹²

Since the introduction of standardized techniques for MV reconstruction by Carpentier and others, numerous technical improvements have been made in MV repair in the last 20 years, particularly in the treatment of anterior and bileaflet MV prolapse.¹ Efforts to find a substitute for elongated or ruptured chordae date back to the 1960s. In 1962, January and coworkers¹³ described a patient operated on “by placing two 00 sutures through the base of papillary muscles and through the margins of the unsupported portion of the mural leaflet.” Frater and associates¹⁴ in 1965 published their experience with experimental and clinical use of autologous pericardium as a chordal substitute.

In the 1980s, ePTFE sutures were evaluated independently at three different institutions (Albert Einstein College of Medicine, New York, NY; Toronto Hospital, Toronto University, Toronto, Ontario, Canada; and Hospital Nacional Marqués de Valdecilla, Santander, Spain) in experimental settings.⁷ The performance of this material was found to be interesting. It permitted infiltration of tissue cells in its porous microstructure, creating a firm adherence of the growing tissue; at the same time, the tissue overgrowth was found to be a self-limiting process.^{7,15} The ePTFE chordae were demonstrated to be flexible, pliable, and resistant after months from implantation, and they were introduced into clinical practice in 1985.^{16,17}

Chordal shortening showed significant limitations at follow-up,¹⁸ and even if chordal transposition demonstrated superior results, it was not always possible to find normal healthy chordae at the opposite site of the prolapsing leaflet. The risk of transferring diseased chordae during MV repair can be avoided with implant of GORE-TEX artificial chordae. Previous reports^{19–21} have shown good results at short and intermediate follow-up. This report represents a 20-year experience, and to our knowledge this is to date the largest homogeneous series of patients to undergo MV repair with chordal replacement with ePTFE for whom the very long-term follow-up beyond 15 years can be analyzed. Neochordal implants could be associated with other classic procedures, such as posterior annuloplasty or quadrangular resection of the posterior leaflet with or without sliding. In our experience, quadrangular posterior leaflet resection has constantly decreased during the most recent years without any increase in rate of failure. Chordal replacement for prolapsed posterior leaflet without quadrangular resection is currently our

Figure 4. Comparison of artificial and native chordae, seen at reoperation after 12 years.

treatment of choice for MV repair in almost all cases. Table 4 shows that quadrangular resection is a protective factor associated with ePTFE chordae, but our change in operative strategy has been motivated by the idea of making the simplest and most effective repair. Our current method saves crossclamp time, preserves valve tissue, and may obtain better coaptation. Furthermore, it may avoid a small ring size annuloplasty, resulting in a larger orifice.

GORE-TEX sutures appear to be an ideal material for synthetic chordal replacement because of their biomechanical properties, which ensure long-term durability and allow surface endothelialization with normal fibrosa and intima.¹⁷ GORE-TEX sutures of 2-0 or 3-0 size seem to lose flexibility with time, and tissue growth makes them stiffer in animal experiments.²² Kobayashi and colleagues⁹ analyzed extracted 4-0 artificial chordae during reoperation and reported thickening and stiffness of the explanted suture. For this reason, they shifted to the 5-0 GORE-TEX suture implant. In 1990 in our institution, Zussa and associates²² demonstrated that GORE-TEX CV 5-0 is a little thicker at explantation from human subjects but maintains length, flexibility, and resistance.

The extensive use of artificial chordae in cases of complex lesions involving the anterior or both leaflets allows MV repair in more than 95% of cases. We reached similar results after 5 years, which is the time necessary for an adequate learning curve. A major role was also played by the improved accuracy of intraoperative transesophageal echocardiography in the surgical planning and postoperative evaluation of MV repair. Transesophageal echocardiography became available in our institution in 1989, but routine intraoperative evaluations have been obtained only since 1991. Previously, epicardial echocardiography was performed in complex cases, but the image quality was poor and sometimes unreliable.

Determination of the exact length of neochordae is a major concern, and several methods have been described.¹⁰ The technique we adopted is highly reproducible in both standard midsternotomy and port-access minimally invasive settings.

Even in cases of acute endocarditis (53 patients), we emphasize that good results can be achieved in a difficult scenario. Neochordae were implanted as a substitute for infected natural chordae. When patches of autologous or heterologous pericardium were used to replace large areas of infected leaflets, artificial chordae were implanted to connect them to the papillary muscles.

On the basis of our experience, we believe that there are no clinical or anatomic contraindications for neochordal implantation, although we have no experience of ePTFE artificial chordal implantation in children. In all our youngest patients (17 patients, age range 15–30 years), the etiology was pure degenerative myxomatous disease; in our opinion, in this subgroup, it is almost mandatory to perform an annuloplasty with a pericardial band, instead of a prosthetic ring, to make the repair most physiologically compatible. Our experience with pericardium is that such repairs are successful and safe, and we have reported the absence of calcification and the presence of complete endothelialization. Cox regression analysis demonstrates that a pericardial band is not predictive of repair failure. Further studies are needed to assess the long-term results and echocardiographic features of the pericardial band.

When prolapse occurs in fibroelastic deficiency, the leaflet tissue is sometimes very thin. It is then mandatory to preserve the posterior mitral leaflet, avoiding quadrangular resection to prevent tissue laceration. Usually the free edge is thicker, and neochordae can be safely anchored at this level.

Freedom from recurrence of moderate or severe MR was high among our patients at 85% at 15 years. Our results are comparable with those of David and colleagues,³ but our experience is 3 years longer. In Flameng and associates' follow-up work,²³ a midterm follow-up study, freedom from severe MR recurrence was low at 7 years (71% $\pm$ 7.4%) relative to values in David and colleagues' series³ (89% $\pm$ 2% at 12 years) and our own. Moreover, in our series all patients had GORE-TEX chordae implanted, whereas in both the other studies, different techniques for MV repair were performed. Even though in literature a very few cases of neochordal rupture or calcification^{24–26} have been reported, in this study the cause of reoperation and recurrent MR was never related to spontaneous rupture or degeneration of implanted GORE-TEX sutures. Regarding the isolated episodes described in the literature, we hypothesize different situations. The ePTFE sutures could be stretched or pinched by forceps or clips at the time of implantation, and this condition may have created a site of weakness. Otherwise, the rupture could have been the consequence of inflammatory process related to a subclinical endocarditis. In 25 reoperations, only in 1 case of acute endocarditis did we detected

a pair of neochordae that ruptured, in this case after being involved in a large erosion of the mural leaflet created by a severe and destructive infective process. According to reports of all reoperations performed in our center, artificial chordae extracted were still as pliable, flexible, and resistant as the native chordae (Figure 4). No calcification has been found in explanted artificial chordae at various intervals after implantation, nor has any been documented at echocardiographic examination. Previously, other authors have found this material to be free of calcification as late as 9 years after implantation.²⁷ No ischemia or rupture of the papillary muscle at the site of implantation was recorded. According to Cox regression analysis, the only independent risk factor for reoperation is the presence of more than mild MR after weaning from cardiopulmonary bypass. Interestingly, in this series anterior leaflet prolapse was not observed as an independent predictor of reoperation, recurrent MR, or mortality. Moreover, assuming that bileaflet MV repair failures were completely due to the anterior component, no significant differences were found between this subgroup and those involving the posterior leaflet alone. Further studies are necessary to assess the precise mechanism of MV failure related to the location of the prolapsing leaflet.

The predictability of the technique and the stability of the results are demonstrated by the low long-term mortality, the low rate of reoperation, and the high rate of freedom from moderate to severe MR at 15 years. Thus artificial chordal implantation, alone or in association with class techniques, has good long-term results.

Limitation

This was a retrospective analysis and thus has some inherent limitations and bias. Follow-up data were obtained from hospital medical records, outside reports, and survey information. We did not personally review any echocardiographic images to assess MR grade but rather trusted that transthoracic echocardiography was performed according to the American Society of Echocardiography guidelines. We recorded death information as obtained through hospital records and public demographic registry. Multivariable analyses were used to control for disparities in preoperative risk factor profile. It may be that these kinds of studies underestimate repair failures, but we believe that the recurrence of significant MR and referral for surgical assessment were closely linked in our patient population.

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Discussion

"A 20-Year Experience of Mitral Valve Repair with Artificial Chordae in 608 Patients." Discussion by James I. Fann, M.D., Stanford, CA.

Dr. James I. Fann (Stanford, CA) Loris, I wish to congratulate you on a comprehensive presentation regarding the use of artificial chordae replacement in the repair of degenerative mitral valve disease. Included in your series is isolated anterior or bileaflet prolapse in nearly half the cases. What is impressive is the number of patients, the excellent early and late results, and the length and completeness of followup. It is believed that artificial chordae replacement in degenerative disease and posterior leaflet prolapse in particular may provide additional chordal support, maintain greater leaflet area, permit for more complex repair, and has the potential of decreased rate of failure.

My first question relates to the percentage of patients who had isolated posterior leaflet prolapse which comprised nearly 50% or 51% of patients who underwent chordal replacement in your group's experience. Here is the question. Do you think that a segmental leaflet resection and reconstruction with annuloplasty without chordal replacement - do you think that would have been sufficient in these patients or is chordal replacement absolutely necessary?

Dr. Salvador. Based on Cox regression analysis, we observed that quadrangular resection of the posterior leaflet is a protective factor only if associated with artificial chordae implant. Actually, I am not sure that the results would be the same without artificial chordae.

In the last years, we performed less frequently quadrangular resection and in this subgroup any redo was needed. In the first decade of this series, when resection was widely adopted, it provided excellent results, that made us pretty happy about performance at long-term follow-up. I don't know honestly how to explain why resection

is a protective factor. I think that at the beginning of the experience, without intraoperative TEE we couldn't precisely analyze mitral valve pathology. So we performed more quadrangular resections of the posterior leaflet, the gold standard at that time, than we do at present. I think that, in future, we will evaluate the long-term results of this strategy, as more and more patients without resection will be included in a study.

Dr. Fann. From the surgical perspective, what technique do you employ to optimize the length or to adjust the chordae. That is, how do you size the length of the chordae? How do you size the ring for the mitral valve repair?

Dr. Salvador. Despite many suggestions that you can find in literature, we always use one simple method. We fill-up the ventricle with saline once the repair is completed. I mean after implanting the ring, quadrangular resection, if needed, or commissural fusion and whatever else you have to repair. At the very end, we fill the ventricle and we decide: to push or pull the leaflet, up or down, until we obtain a satisfactory coaptation. This is the only method we use. After acquiring an adequate experience we do not even pay so much attention to the length because it becomes something instinctual. I don't think is so fundamental to execute scientific measurements about distance between papillary muscles and annulus or something like this.

Dr. Fann. Do you oversize the annulus when you do the annuloplasty? I know you use the ...

Dr. Salvador. Most of our patients had autologous pericardium band implant and we adopt a very simple way to measure it, using the Carpentier sizers based on the patient's Body Surface Area. We assume that a BSA under 1.60 Square Meters, need the Carpentier's number 32 and we cut the band around that sizer. Between 1.60 and 1.80 we use a 34 sizer and above 1.80 the 36 sizer.

Dr. Fann. And finally you report that a total of 12 patients with more than 2+ MR were found immediately after surgery. What was the cause in these patients other than the those patients that you reported that had SAM that also had 2+ MR and how were these patients treated postoperatively?

Dr. Salvador. Actually, the patients were discharged! Mostly, this entity of post-operative MR was observed at the beginning of the experience, however in a small percentage of patients: 12 out of 608. First of all, I repeat, in the mid '80, it was difficult to have the echo in OR. At that time we had only normal transthoracic echo so we accepted this grade of insufficiency if it was found after leaving the OR. Right now it is a very rare event that a patient is discharged with such grade of insufficiency and there must be a very compelling reason. Today, it's very rare also to be discharged even with 1+. At the beginning of the experience we accepted it, considering that, in some patients, a second run of cardiopulmonary bypass would have been more risky than a 2+ mitral regurgitation.

Dr. Fann. Loris, thank you very much for an insightful presentation. I appreciate it.

Dr. Salvador. Thank you.

APPENDIX E1: Variables included in Cox regression analysis of risk factors for death, reoperation, and presence of significant mitral regurgitation

Demographic variables

Age

Sex

Mitral valve disease

Etiology

Prolapse or rupture of anterior leaflet

Prolapse or rupture of posterior leaflet

Prolapse or rupture of bileaflets

Annular calcification

Left ventricular function

Chronic heart failure

History of myocardial infarction

Cardiac comorbidity

Preoperative atrial fibrillation

Number of coronary arteries with more than 50% stenosis

Family history of coronary artery disease

Aortic valve disease

Ascending aorta dilation

Tricuspid valve disease

Repair

Date of repair

Use of annuloplasty

Type of annuloplasty

Leaflet resection

Sliding leaflet repair

Anterior leaflet chordal implant

Posterior leaflet chordal implant

Bileaflet chordal implant

Sentinel neochordal implant

Number of sentinel neochordae

Repair of residual defect in leaflet coaptation

Use of intraoperative echocardiography

Associated procedures

Appendage closure

Patent foramen ovale or interatrial septal defect closure

Coronary artery bypass grafting

Surgical ablation of atrial fibrillation

Tricuspid annuloplasty

Aortic valve surgery

Ascending aorta surgery

Crossclamp time

Cardiopulmonary bypass time

Perioperative mitral regurgitation

Perioperative morbidity