Replacement of Chordae Tendineae with Polytetrafluoroethylene (PTFE) Sutures in Mitral Valve Repair: Early and Long-Term Results

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Background and aim of the study: **A variety of reliable techniques are now available for chordal disease management and repair of the anterior mitral valve leaflet prolapse. The study aim was to review the authors' experience with polytetrafluoroethylene (PTFE), using a standardized technique for length adjustment, and to analyze the long-term results in patients who underwent mitral valve repair.**
Methods: **A total of 111 patients (mean age 56.2 ± 16.1 years) underwent mitral valve repair with PTFE neochordae, in addition to a variety of other surgical procedures. Etiologies were degenerative in 82 patients (73.9%), Barlow disease in 13 (11.7%), rheumatic in 10 (9%), and infection in six (5.4%). Prolapse of the anterior leaflet was present in 78 patients (70.3%), of the posterior leaflet in 15 (13.5%), a bileaflet prolapse was present in 12 (10.8%), and a commissural prolapse in six (5.4%). In all cases the anterior annulus was used as the reference level in order to assess the appropriate length of the PTFE neochordae.**
Results: **The mean number of PTFE neochordae used was 6 ± 4 per patient. In-hospital mortality was 1.8% (n = 2); mean follow up was 36.8 ± 25.6 months (range: 12-94 months). There were no late deaths. At five years postoperatively the patient overall survival was 98.2 ± 1.8%, freedom from reoperation rate 100%, and freedom from grade 1+ mitral regurgitation rate 97.2 ± 2.8%. There were no documented thromboembolism or hemorrhagic events.**
Conclusion: **In degenerative and myxomatous mitral valve disease, leaflet prolapse can be successfully repaired by implantation of PTFE neochordae. Both immediate and long-term results proved the versatility, efficiency and durability of this technique.**

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For more than two decades, the repair of degenerative anterior mitral leaflet (AML) prolapse has mostly been performed with a form of chordal management, while posterior mitral leaflet (PML) prolapse has been widely dealt with by quadrangular resection and annulus remodeling. Although a variety of reliable techniques is currently available to the surgeon for chordal disease management and repair of leaflet prolapses, each technique has its limitations and difficulties. For example, chordal shortening is technically demanding and the quality of shortened chordae is questionable, while chordal transfer is limited by the availability of secondary chordae or the frequent disease of PML (for the flip-over technique). More recently, polytetrafluoroethylene (PTFE) neochordae have been introduced to overcome those difficulties and limitations, and these are becoming increasingly popular due to their availability, simplicity, and long-term durability (1-4). The main technical issue with artificial neochordae, however, is to determine the appropriate length. Several techniques for ensuring the correct length have been described previously (5). Along with increasing experience with PTFE neochordae, the indications for their use are constantly reviewed and have been extended to PML prolapse, to rheumatic patients, and even to those with active endocarditis.

The study aim was to review the present authors' experience with PTFE neochordae, using a standardized technique to adjust the length (6), and to analyze the early and late outcomes of patients who underwent mitral repair with PTFE chordae.

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Clinical material and methods

Patient demographics

Between January 1996 and December 2002, a total of

540 patients was operated on for mitral valve repair at the authors' institution. Of these patients, 111 (21%) underwent repair with PTFE neochordae, in addition to a variety of other surgical procedures; these patients form the cohort of the present study. The preoperative clinical characteristics of patients are summarized in Table I. As part of the preoperative evaluation, angiography was performed in patients aged >40 years. Associated procedures were performed in 30 patients (27%); details are listed in Table II.

Following the induction of anesthesia, transesophageal echocardiography (TEE) was performed preoperatively in all patients, of whom 82 (73.9%) had a degenerative disease (myxomatous degeneration of the mitral valve), 13 (11.7%) had Barlow disease, and eight (7.2%) were asymptomatic. The large majority of patients (89.2%) were in NYHA functional classes II or III.

Surgery

Valve exposure

After median sternotomy, the right pericardium was suspended in such a way that it completely covered the right edge of the sternum. While opening the sternal retractor, the two vena cava were externalized so that the heart was truly rotated towards the left side. The left atrium was entered through a longitudinal incision of the interatrial groove. A self-retaining Kapp-Cosgrove device (Kapp Surgical Inc., Cleveland, OH, USA) with its three retractors was positioned systematically. After adequate exposure, a careful examination of the mitral valve and its components was undertaken intraoperatively.

Table I: Preoperative clinical characteristics of the study population.

Parameter	Value
Gender	
Male	72 (64.8)
Female	39 (35.2)
Age (years)*	56.2 ± 16.1 (19-80)
Etiology	
Degenerative	82 (73.8)
Barlow	13 (11.7)
Rheumatic	10 (9.1)
Infective	6 (5.4)
NYHA class	
I	8 (7.2)
II	38 (34.3)
III	61 (54.9)
IV	4 (3.6)
Atrial fibrillation	37 (33.3)
LVEF (%)*	59.3 ± 10.5 (33-80)

*Values are mean ± SD (range).
Values in parentheses are percentages.
LVEF: Left ventricular ejection fraction.

PTFE implantation strategy

Papillary anchoring of artificial neochordae was performed after all resections (posterior leaflet) and additional maneuvers (such as a sliding plasty) had been completed, but before reconstruction and ring implantation. In order to avoid any restrictive motion, the native chordal distribution, both on the papillary muscles and on the free margins, was respected; the neochordae supporting the right half of the mitral valve were anchored on the posterior (medial) papillary muscle, and those supporting the left half were anchored on the anterior (lateral) papillary muscle. In order to improve papillary muscle exposure and facilitate chordal anchoring, a stay suture (Ethibond 2/0; Ethicon Inc.) was passed through the papillary head and a gentle upward traction was exerted. Finally, care was taken to distribute the papillary anchoring on different fibrous heads in order to avoid any risk of ischemia.

The free margin anchoring was performed using a previously described technique (6), taking the anterior annulus as the reference level to adjust the length of the anterior chordae. This provides a simple but accurate means of obtaining the correct length as the tip of the papillary muscle is analogous to the center of a circle with the chordal length analogous to the radius, and the curvature of the leaflet analogous to that of the circle. The implantation procedure may be divided schematically into five steps:

1. A double-armed Gore-Tex CV5 suture is passed through the fibrous portion of the papillary muscle head.
2. The two arms must be tied with at least five knots, as described previously by David et al. (2).
3. Each arm of the suture is then passed twice at the free edge of the prolapsing segment of the leaflet, but on the second passage the suture is crossed under

Table II: Associated procedures (n = 30).

Procedure	No. of patients
CABG	11 (9.9)
Aortic valve sparing	8 (7.2)
Aortic valve replacement	1 (0.9)
Tricuspid valve plasty	5 (4.5)
ASD closure	2 (1.8)
Ross operation	
Ascending aorta replacement	1 (0.9)

Values in parentheses are percentages.
ASD: Atrial septal defect; CABG: Coronary artery bypass graft.

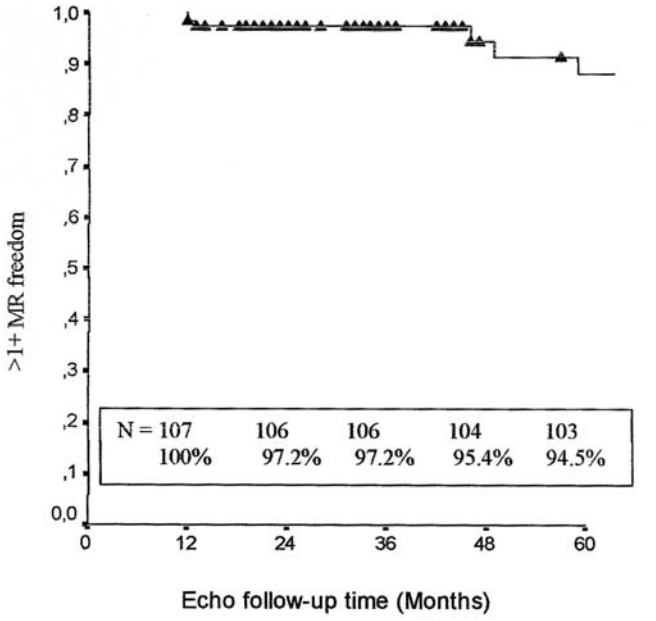

Figure 1: Freedom from grade >1+ mitral regurgitation at follow up echocardiography.

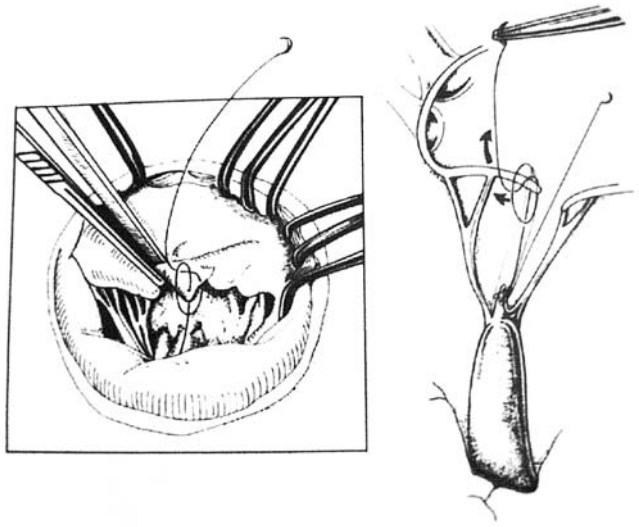

Figure 2: Each arm of the suture is passed twice through the free margin of the prolapsing segment. On the second passage, attention is made to loosely lock the suture.

the loop and not tightened (Fig. 2); attention is paid to loosely lock the suture to create a half-hitch knot and prevent slippage of the PTFE.

4. The free margin is brought to the level of the anterior annulus and firmly maintained by forceps, while the suture is tightly locked (Fig. 3).
5. The two arms are passed again through the leaflet and tied on the ventricular side.

In case of diffuse bileaflet prolapse, a quadrangular resection of P2 was performed (with or without a sliding plasty), the anterior leaflet was then repaired with PTFE, the posterior leaflet reconstructed, and finally P1 and P3 (if needed) were repaired with additional PTFE neochordae, with the posterior annulus as reference point. In older patients with localized or diffused posterior annulus calcifications associated with posterior leaflet prolapse, the implantation of PTFE neochordae was performed in order to avoid an extensive decalcification, especially in case of associated procedures.

When the mitral valve repair was accomplished, and before implantation of a prosthetic ring, the valve was water-tested and additional PTFE sutures were placed in order to obtain perfect valvular competence. In patients with rheumatic disease, notwithstanding that the leaflet tissue was of good quality and the rheumatic process limited to the commissure, resection of the diseased commissure and its replacement with a tricuspid autograft were performed. The PTFE chordae were anchored on the mitral papillary head and on the free margin of the autograft to relieve tension on the sutures. Any diseased chordae were excised and replaced with PTFE chordae.

In patients with valve endocarditis the PTFE chordae were used to replace the ruptured chordae, or to support a pericardial patch used to reconstruct the leaflet tissue.

Follow up

Follow up was obtained by telephone interviews with patients and questionnaires to the referring cardiologist. All patients underwent postoperative transthoracic echocardiography at annual intervals; this was performed either in the echocardiography laboratory (n = 77) or by the referring cardiologist (n = 32). All patients received warfarin sodium postoperatively, maintaining the International Normalized Ratio at between 2.0 and 2.5. Anticoagulation was discontinued after three months, except for those patients with atrial fibrillation. Follow up was 100% complete; the mean follow up period was 36.8 ± 25.6 months (range: 12 to 94 months).

Statistical analysis

Statistical analysis was performed using the SPSS 11.0 statistical software (SPSS Inc., Chicago, IL, USA). Continuous data were expressed as mean ± SD, and categorical data as percentages. An unpaired *t*-test was used for continuous variables, and Fisher's exact test for comparison of nominal data. An analysis for freedom from mitral regurgitation (MR) was performed using the Kaplan-Meier method. A p-value <0.05 was considered to be statistically significant.

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Results

The mean cross-clamp time was 85.0 ± 32.7 minutes (range: 30 to 196 min). Data related to the implantation of PTFE chordae and additional mitral valve techniques are listed in Tables III and IV, respectively. During intraoperative TEE, nine patients (8.1%) were found to have moderate to severe residual MR, and each underwent a second pump run to achieve satisfactory repair. No residual MR could be attributed to any undercorrection (excess neochordal length). A restrictive valve motion due to an overcorrected prolapse by too-short chordae was responsible for residual MR in only one patient, and the shortened chordae were replaced.

Mortality and morbidity

Early

In-hospital mortality was 1.8% (n = 2). One patient with multivessel disease succumbed to low cardiac output syndrome, and one died from multiorgan failure. Re-exploration for bleeding was performed in five patients (4.6 %), and a pacemaker was implanted in one patient. Ultimately, four patients developed acute renal failure (hemodialysis was required in only two cases), and one patient experienced a stroke but made a full recovery.

Late

There were no late deaths, and overall actuarial survival at five years was 98.2 ± 1.8%. There were no documented thromboembolism or hemorrhagic events; six patients (5.5%) suffered from new-onset atrial fibrillation. No patient required reoperation, and freedom from grade >1+ MR was 94.5% (Fig. 1).

NYHA functional class

At follow up, the postoperative NYHA functional class was significantly improved compared to the preoperative period ($p < 0.001$). In total, 100 patients (91.7%) were in class I, six (5.5%) in class II, and three (2.8%) in class III.

Table III: Gore-Tex chordae implantation data.

Site of implantation	No. of patients
A1	3 (2.7)
A2	79 (71.2)
A3	8 (7.2)
P1	2 (1.8)
P2	5 (4.5)
P3	2 (1.8)
Bileaflet repair	12 (10.8)

Values in parentheses are percentages.

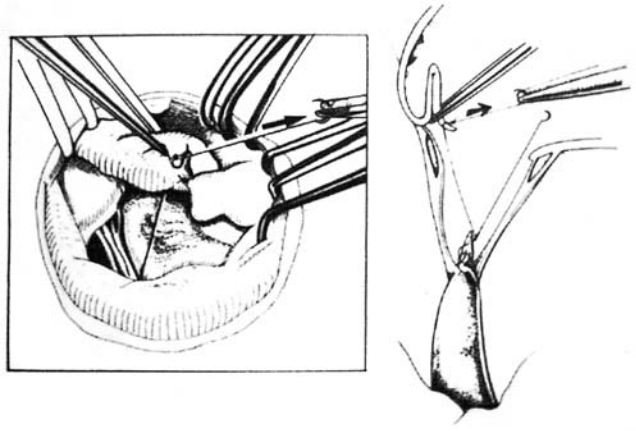

Figure 3: After the free margin is brought to the level of the anterior annulus and firmly maintained, the suture is tightly locked.

Echocardiography

Transthoracic echocardiography was performed in all patients at follow up. Only three patients had grade 3+ MR, and no patient had grade 4+. In total, 80 patients had no residual MR, 20 had grade 1+, and six had grade 2+.

Discussion

During the past 15 years, innovative techniques for chordal replacement have been introduced by several groups (7-9). These techniques have significantly increased the likelihood of performing a mitral valve

Table IV: Additional mitral valve repair techniques.

Technique	No. of patients
Triangular resection	37 (33.3)
Commissuroplasty	19 (17.1)
Decalcification	17 (15.3)
Anterior	10 (9)
Posterior	3 (2.7)
Commissural	4 (3.6)
Sliding plasty	10 (9)
Papillary muscle remodeling	4 (3.6)
Chordal transfer	3 (2.7)
Quadrangular resection P1	8 (7.2)
Quadrangular resection P2	26 (23.4)
Quadrangular resection P3	1 (0.9)
Annuloplasty	
26 mm	4 (3.6)
28 mm	4 (3.6)
30 mm	15 (13.6)
32 mm	29 (26.1)
34 mm	30 (27.0)
36 mm	29 (26.1)

Values in parentheses are percentages.

repair, and many studies have demonstrated their excellent long-term durability (1-4). Consequently, chordal replacement has become more popular and increasingly used in flail mitral valve prolapse. Moreover, there is a constant broadening of its indications with regard to the prolapse localization (anterior or posterior), as well as to the valve etiology (degenerative, rheumatic or endocarditis) (1,2,4).

Chordal replacement was introduced by David in 1985, primarily to repair the anterior or mixed (anterior/posterior) prolapse (10). Based on that initial report, several techniques have been described to ensure an appropriate length to the neochordae. In 2000, the present authors described a simple technique to adjust chordal length, based on the hypothesis that the anterior mitral annulus is the reference level. During surgical assessment of the different mitral valve segments prior to repair, it is always possible to verify that, in the absence of prolapse, when the anterior free margin is moved anteriorly it will always be at the same level as the anterior annulus. The present analysis largely supported this hypothesis: only one patient had an overcorrection of the prolapse (during the early stage of the study, due most likely to the learning curve), while for the eight patients who required a second run, the residual MR was not related to the neochordal length. In 2002, Duran and Pekar described a new technique taking almost the same reference level (5).

It is believed that the present technique allows visual control of the papillary muscles and, consequently, of the length of the chordae. Moreover, the testing of valve repair competence before ring implantation allows for the placement of some additional neochordae if needed. At present, the versatility of neochordae has led some centers to abandon the 'gold standard' technique (the 'French correction') of the posterior leaflet in favor of systematic neochordae implantation (11). The present authors also use chordae implantation for the posterior leaflet in selected circumstances, including annular calcification (localized or diffuse), associated with a prolapse, in patients with extensive prolapse of P2 when resection might compromise the amount of the remnant valve, and finally in concomitant procedures when an expeditious technique is preferred. The reference point of the implanted neochordae is represented by the native chordae supporting the non-prolapsed scallops of the posterior leaflet; in case of prolapse of all posterior leaflets, the anterior leaflet serves as the reference point.

The management of Barlow disease with a diffuse prolapse remains a matter of debate; indeed, some surgeons still consider this to be a contraindication to repair. At the authors' institution, Barlow disease is always repaired, proceeding systematically to the resection of P2, together with a sliding plasty and the implantation of PTFE chordae on the anterior leaflet. By using an intraoperative water test, the decision can be made as to whether additional chordae are needed for P1 or P3. The trend in moving towards an extensive use of PTFE chordae in mitral surgery does not mean an abandonment of the French correction (12). Indeed, the classical posterior prolapse will still be approached with Carpentier's technique, using chordal transfer, but chordal or papillary shortening will no longer be performed. The technical simplicity, efficacy and long-term success of the neochordae technique can be seen as the beginning of a new strategy. Recently, David et al. reported the first case of rupture of neochordae 14 years after implantation in a rheumatic valve, wherein the calcification and rupture of a PTFE matrix had occurred due to progression of the rheumatic disease (13). Recently, the present authors (unpublished data) operated on a patient for a recurrent anterior prolapse. The patient had benefited from PTFE chordae implantation two years earlier for an anterior prolapse (at another institution), but at reoperation a ruptured PTFE chordae was discovered, most likely caused by a metal clip that had been used to ensure the correct length and, in time, had caused microtrauma.

Among the present patients early mortality was low, and in the selected subgroup of patients with degenerative disease (n = 82) it was less than 1%. One concern about chordae implantation is the long-term stability of an immediately successful repair; this is raised mainly because postoperative remodeling of the left ventricle and the behavior of the implanted artificial chordae. The question remains as to whether an appropriate operative length of the PTFE chordae persists over an extended follow up. The present results in terms of MR recurrence support this concept. Freedom from reoperation among the present patients compared favorably with most published series, and was 100% at follow up. For example, Kobayashi et al. (14) reported five patients who required reoperation, the indication being congestive heart failure (n = 4) and hemolysis (n = 1). Breakage of the replaced PTFE chordae or tearing of the leaflet or papillary muscle at the attachment of PTFE chordae did not occur in patients with recurrent MR, and the actuarial reoperation-free rates at five and 10 years were 94.3 ± 2.8% and 81.7 ± 9.1%, respectively (14). In their series, Gillinov et al. (15) and Braunberger et al. (16) reported that about 50% of reoperations occurred within the first year after repair, with a median time to reoperation of 2.5 years. Because of an absence of reoperations among the present patient group within this time frame, the present authors are both optimistic and confident of the long-term outcome. Before the present study, and to the best of the authors' knowledge, only Flameng et al. (17) had

reported a 100% complete echocardiographic follow up in a series of patients who underwent mitral valve repair for degenerative valve disease. In this study, at eight years after repair, clinical outcome was excellent, survival was 90.9 ± 3.2%, freedom from reoperation 94.2 ± 2.3%, and freedom from anticoagulation bleeding and thromboembolic events 90.4 ± 2.7%. However, freedom from non-trivial MR (grade >1/4+) was 94.3 ± 1.6% at one month, 58.6 ± 4.9% at five years, and 27.2 ± 8.6% at seven years. This showed that the durability of a successful mitral reconstruction for degenerative mitral valve disease was not constant - a point which cardiologists often cite as a reason not to refer patients for mitral repair (17). The recurrence of MR grade >1+ occurred at a rate of 8.3% per year. In the study by Flameng et al. (17), the majority of patients had a posterior leaflet prolapse (65%), and the situation was similar in a more recent study by David et al. (18) which included 701 patients with 93.4% echocardiographic follow up. Here, freedom from grade 3+ or 4+ MR at 12 years was 73%, with better outcome among patients with posterior leaflet repair (80 ± 4%) than in those undergoing anterior leaflet repair (65 ± 8%) or bileaflet repair (67 ± 6%). The main difference between the present study and previous investigations was that 81.1% of the present patients underwent anterior leaflet repair. Moreover, the good long-term results supported the more common notion that mitral repair can be performed with predictable stability - at least in the first five years - even when using artificial chordae, in patients with a recurrence of MR grade >1+ of 1.9% per year. The present excellent long-term results could also be explained by a policy regarding residual MR during the repair procedure. Currently, the preference is to perform a second pump run in the presence of greater than mild MR, and this is always carried out when there is an eccentric regurgitant jet.

In conclusion, in degenerative and myxomatous mitral valve disease, leaflet prolapse can be durably repaired with implantation of PTFE neochordae, and with the anterior annulus as a reference level. The excellent immediate results prove the success of this technique, while the long-term results highlight its efficiency and stability over time.

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Meeting discussion

DR. J. SCOTT RANKIN (Nashville, Tennessee, USA): This excellent study contributes to the growing trend of using artificial Gore-Tex chords for prolapse. It seems from your conclusions that you are now using it for all prolapses - is that the case? You seem to have given up leaflet resections and sliding plasties, which has been our approach since 1996, which we published last year in the Journal of Heart Valve Disease. I feel very strongly that because of your stability data, the increased applicability, and lack of systolic anterior motion and outflow tract obstruction, that uniform artificial chordal replacement should be the primary technique now for all prolapses. Do you have any comments?

DR. BRUNO CHIAPPINI (Brussels, Belgium): I completely agree with you. We must improve not only the use of Gore-Tex chordae, but also our experience in that direction.

DR. BLASE A. CARABELLO (Houston, Texas, USA): You performed postoperative echocardiography on all of these patients, but what was the postoperative ejection fraction?

DR. CHIAPPINI: It was slightly increased - from a mean of 56% preoperative to 66% postoperative.

DR. CARABELLO: That's quite good. It's a shame that cardiologists still refer patients to surgery in NYHA class III, which I feel is way too late in the course of this disease. Some of those patients may have had an acute chordal rupture, and nothing can be done about that. But it's a shame that we all still wait so long before referring patients for surgery - and it's the same on both sides of the Atlantic.

DR. CARLOS DURAN (Missoula, Montana, USA): At present, almost any other technique of chordal shortening - let alone rupture - can be treated with Gore-Tex. Regarding durability, does anybody here have a patient where the Gore-Tex has torn or broken, because I still have not seen a single failure of Gore-Tex reported - only of the repair. I have one specific question about using Gore-Tex in rheumatic cases. Do you replace all the matted and shortened chords with Gore-Tex, or do you use it in a mixed rheumatic lesion where there is much fibrosis? You extend the cusps of the anterior leaflet, but what about the chordae?

DR. DAVID H. ADAMS (New York, USA): At what point do you actually use Gore-Tex chordae? I noticed that your echocardiograms showed billowing of the body of A2, but the margin of the leaflet was in the annular plane. Some part of the leaflet was prolapsing but the margin was not. So when do you actually decide to add a chorda, because that patient may have been OK with just an annuloplasty and reduction of the posterior leaflet prolapse.

DR. CHIAPPINI: When there is important flailing of the leaflet above the mitral annulus plane we decide to place Gore-Tex chordae. We decide the exact length of the neo-chordae by using the anterior mitral annulus as a reference level.

DR. ADAMS: So you add the Gore-Tex chordae before performing a ring?

DR. CHIAPPINI: Yes, of course.

DR. WILLIAM F. NORTHRUP, III (St. Paul, Minnesota, USA): Are your knots on the leaflet, or down on the papillary muscle? Which is your preference?

DR. CHIAPPINI: On the leaflet.

DR. NORTHRUP: On the underside or on the atrial side?

DR. GEBRINE EL KHOURY (Brussels, Belgium): The knots are placed on the ventricular side of the leaflets. I must respond to Dr. Duran about the rupture of Gore-Tex. Some months ago I operated on a patient who had undergone surgery at another hospital with Gore-Tex on the anterior leaflet, and two years later there was a recurrence of mitral regurgitation. At surgery there was rupture of the Gore-Tex, but at the level of the ties there was a metal clip, so there was some diastolic micro-traumatism between the clip and the Gore-Tex. So I think we should question the use of metallic clips to secure the knots for Gore-Tex. Regarding rheumatic patients, it depends on the quality of the tissue - if for the valve it is acceptable and the main disease is at the level of the subvalvular apparatus, we would resect the diseased chordae and replace them with Gore-Tex.