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A new technique to adjust the length of artificial chordae during mitral anterior leaflet repair

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Abstract

Background: Length measurement of artificial chordae remains a critical step during mitral valve repair (MVr). The aim of this study is to assess the effectiveness of a new length measuring technique.

Methods: All consecutive patients with anterior leaflet prolapse/flail who underwent MVr using the described method between January 2020 and January 2022 at our institution were included in the analysis. Clinical and transesophageal echocardiography data were collected postoperatively and at 1-year follow-up. The primary outcome was freedom from mitral regurgitation (MR). Secondary outcomes were presentation with New York Heart Association (NYHA) class <2 and leaflet coaptation length ≥10 mm.

Results: Of 25 patients, 16 (64%) were males. A total of 15 (60%) had isolated anterior leaflet disease, while 10 (40%) had concomitant posterior involvement. Twenty patients with isolated MR (80%) underwent right anterior mini-thoracotomy, while 5 (20%) with associated valvular or coronary disease underwent sternotomy. The median number of chordae implanted was 2 [1–4]. Postrepair intraoperative MR grade was 0 in 23 patients (92%) and 1 in 2 (8%). Thirty-day mortality was 0%. De novo atrial fibrillation was 20%. At follow-up, mortality was 0%. No patients presented with moderate or severe MR. A total of 22 patients (88%) were in NYHA class I, while 3 (12%) in class II. The coaptation length was 11 ± 1 mm.

Conclusions: The short-term outcomes of the described technique are good with adequate leaflet coaptation in all treated patients. Long-term results are needed to assess the stability and durability of this repair technique.

KEYWORDS

artificial chordae, length measurement, mitral valve repair

Abbreviations: ePTFE, expanded polytetrafluoroethylene; MR, mitral regurgitation; MVr, mitral valve repair.

Giuseppe Nasso and Nicola Di Bari contributed equally.

Mario Gaudino and Giuseppe Speziale contributed equally as senior authors.

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1 | INTRODUCTION

Mitral valve repair (MVr) is regarded as the optimal surgical approach to treat degenerative mitral regurgitation (MR).[1,2]

Classical resection repair techniques popularized by Carpentier are highly reproducible and probably the most commonly used techniques for MVr.[3] However, nonresectional techniques using expanded polytetrafluoroethylene (ePTFE) chordal replacement have the advantage of preserving the subvalvular apparatus and are being increasingly adopted, especially in the setting of anterior prolapse.[4–7] With this approach, length adjustment of artificial chordae is a critical and at times challenging step. Technical errors in determining the appropriate chordal length can lead to repair failure and early MR recurrence.[8,9]

Herein, we present our initial experience with a simple and reproducible technique for adjustment of the length of artificial chordae during MVr in a population with anterior leaflet disease.

2 | MATERIALS AND METHODS

This study was approved by the Institutional Review Board (Internal protocol, decision 2019 December) at Anthea Hospital GVM Care & Research (Bari, Italy) and need for patients' informed consent was waived.

A review of prospectively collected data from our departmental database was conducted to identify all consecutive patients with anterior leaflet prolapse or flail who underwent MVr using the described technique between January 2020 and January 2022.

MR was graded according to the 2017 European Society of Cardiology Guidelines for the management of valvular heart disease.[10] Clinical and transesophageal echocardiography data were collected postoperatively and at 1-year follow-up.

2.1 | Surgical technique

All interventions were performed under general anesthesia using orotracheal intubation with a single- or double-lumen tube for selective exclusion of the right lung. Mini-thoracotomy was the preferred approach in patients with isolated MR, while standard median sternotomy was used in patients with associated coronary artery or valve disease.

All procedures were performed using cardiopulmonary bypass with double venous cannulation and bicaval snaring and mild hypothermia (34°C–36°C). The priming solution contained 1250 ml of Ringer's crystalloid acetate solution. The perfusion system consisted of a Stöckert S5 heart-lung machine. To obtain myocardial protection, a closed circuit for cold antegrade blood cardioplegia (4°C) with heat exchanger, an infusion syringe pump in series and Saint Thomas solution with procaine were used and repeated every 30 min. Access to the mitral valve was via Guiraudon's biatrial techniques for median sternotomy or left atriotomy approach, in patients treated by right mini-thoracotomy.

2.2 | Artificial chordae length measuring technique

The five key steps of our repair technique are described below:

Step I After identification of the prolapsing segment and of the elongated or ruptured chordae of the anterior leaflet, one or more 4-0 ePTFE chordae are passed through the fibrous head of the anterior papillary muscle. To avoid tearing of the papillary fibrous portion, two pledgets are used (before and after passing the suture through the papillary muscle).

Step II The two limbs of the ePTFE suture are then passed twice through the free edge of the prolapsing anterior leaflet from the ventricular to the atrial side at a distance of approximately 5 mm, creating two loops that are left untied.

Step III A single Ethibond suture is passed through the anterior annulus at a location corresponding to the diseased leaflet segment (A1, A2, or A3). The Ethibond's needle tips are then individually slipped through the two loops of the previously implanted artificial neo-chord, passed through the posterior annulus of the opposing segment (P1 if A1 is diseased, P2 if A2, or P3 if A3) at a distance of a few millimeters from one another, and tied to create a temporary guide for chordal attachment (Figure 1A). To avoid injury to the surrounding structures (circumflex artery, aortic valve), special attention is paid when anchoring the Ethibond suture to the anterior and posterior annulus.

Step IV The two free ends of each neo-chord are then adjusted to the height of the annular Ethibond suture and tied right above it (Figure 1B).

Step V Before the removal of the guide, the neo-chord is inspected and further adjusted, if needed. The annular Ethibond suture is then cut (Figure 2A) and the guide is removed (Figure 2B,C).

The repair was then completed by addressing any concomitant posterior leaflet lesions with resectional techniques. In all cases, a complete MEMO 3D ring (Livanova PRT) was implanted.

2.3 | Statistical analysis

Continuous variables are reported as mean ± standard deviation for normally distributed data or median and lower/upper quartiles for skewed data. Categorical variables are reported as count and percentage. All analyses were performed using R 2.13.2 software (R Development Core Team, Vienna, Austria).

3 | RESULTS

A total of 25 patients were identified, of whom 16 (64%) were males. The mean age was 68 ± 4.2 years. Most patients presented with hypertension (20, 80%) and hypercholesterolemia (13, 52%). The prevalence of diabetes was 36%. Six patients (24%) presented with renal dysfunction, while 1 (4%) was in dialysis. Nine patients were in atrial fibrillation preoperatively (36%) and the mean ejection

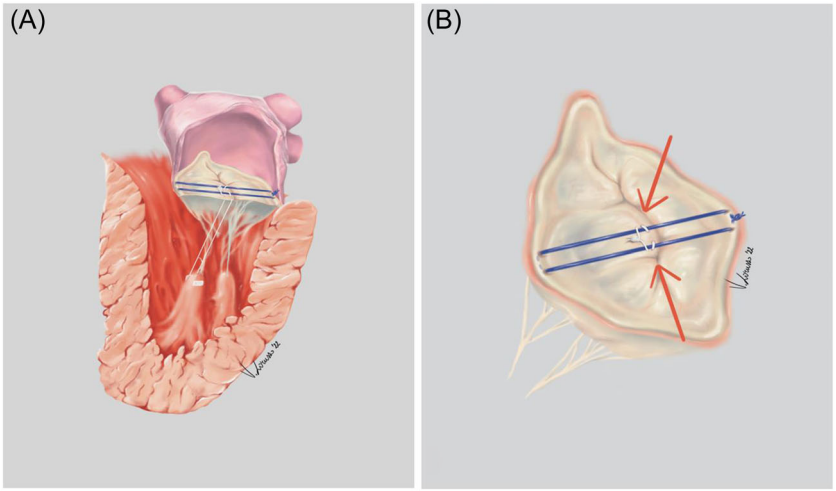

FIGURE 1 (A) A single Ethibond suture is passed through the anterior annulus at a location corresponding to the diseased leaflet segment (A1, A2, or A3). The Ethibond's needle tips are individually slipped through the two loops of the previously implanted artificial neo-chord, passed through the posterior annulus of the opposing segment, and then tied separately to create a temporary guide for chordal attachment. (B) The two ends of each neo-chord are adjusted to the height of the guide and tied right above it (Artist representation of the tied ends of the artificial neo-chord)

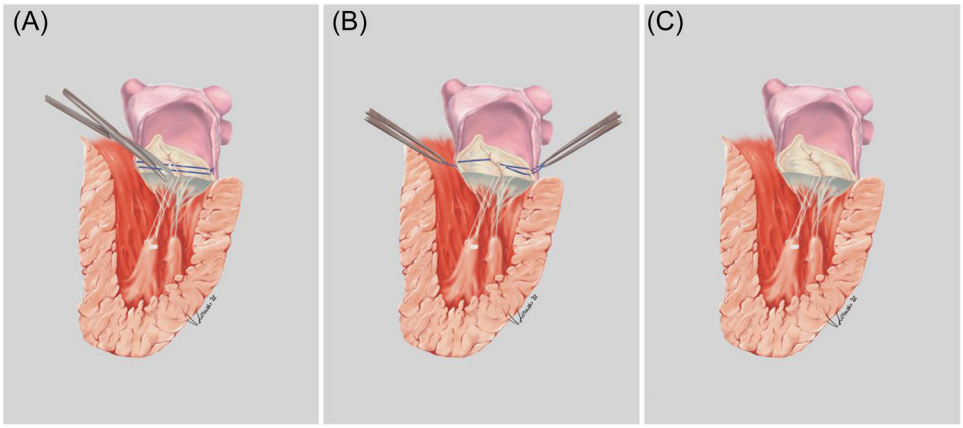

FIGURE 2 (A) After final adjustment of the neo-chord the annular Ethibond suture is cut. (B) The guide is removed. (C) Artist representation of the mitral valve at the end of the procedure

fraction was 45 ± 10%. A total of 15 patients (60%) had isolated anterior leaflet disease, while 10 (40%) had concomitant posterior leaflet involvement. A total of 20 patients (80%) had A2 prolapse (12 prolapses and 8 flails), 3 had A1 prolapse (3 prolapses) and 2 had A1 + A2 prolapse (1 prolapse and 1 flail). Of the 10 patients (40%) with concomitant posterior leaflet involvement, 3 (30%) had P3 prolapse and 7 (70%) had P2 prolapse/fail. The length of the anterior leaflet was 30 ± 5 mm and of the posterior leaflet 16 ± 4 mm. Antero-posterior diameter of mitral valve annulus was 47 ± 7. Three patients (12%) had concomitant aortic valve disease, while 2 (8%) had concomitant coronary artery disease. The mean EuroSCORE was 5.69 ± 2.41. Detailed patient characteristics are shown in Table 1.

The 5 patients (20%) presenting with concomitant aortic valve or coronary artery disease underwent median sternotomy, while all remaining patients (20, 80%) underwent right anterior mini-thoracotomy. Three patients (12%) received aortic valve replacement with a bioprosthesis, 2 (8%) received coronary artery bypass grafting, and 6 (24%) underwent ablation of atrial fibrillation.

All patients received mitral annuloplasty and the median ring size was 34 [32–38] mm. The median number of artificial chordae implanted was 2 [1–4]. Postrepair intraoperative MR grade was 0 in 23 patients (92%) and 1 in 2 patients (8%). Intraoperative data are shown in Table 2.

There was no operative mortality. De novo atrial fibrillation was detected in 5 patients (20%) and was treated pharmacologically, although electrical cardioversion was necessary in one case (4%). One patient (4%) required mechanical ventilation time for more than 24 h. Inotropic support was required in one case (4%). The mean stay in the intensive care unit was 3 ± 1 days, while the mean length of

TABLE 1 Preoperative characteristics

Variable	N = 25
Age (years)	68.5 ± 4.2
Female sex	9 (36)
Male sex	16 (64)
Hypertension	20 (80)
Hypercholesterolemia	13 (52)
Diabetes	11 (44)
• Noninsulin-treated	5 (20)
• Insulin-treated	5 (20)
• Diet/exercise	1 (4)
Smoking habit	
• Current	6 (24)
• Ex	12 (48)
PVD	0 (0)
AF	9 (36)
COPD	3 (12)
Renal dysfunction	6 (24)
Dialysis	1 (4)
EF (%)	45 ± 10
EuroSCORE II	5.69 ± 2.41
Isolated MR	20 (80%)
Combined MR	5 (20%)
• MR + AV disease	3 (12%)
• MR + CAD	2 (8%)
Mitral leaflet disease	
Anterior	25 (100)
• Prolapse	16 (64)
• Flail	9 (36)
• Prolapse/flail	0 (0)
• A1	3 (12)
• A2	20 (80)
• A3	0 (0)
• A1 + A2	2 (8)
• A2 + A3	0 (0)
Posterior	10 (40)
• Prolaspe	3 (30)
• Flail	0 (0)
• Prolapse/flail	7 (70)
• P1	0 (0)
• P2	7 (70)
• P3	3 (30)
• P1 + P2	0 (0)
• P2 + P3	0 (0)
• Length of the anterior leaflet (mm)	30 ± 5
• Length of the posterior leaflet (mm)	16 ± 4 mm
• Antero-posterior diameter of mitral valve annulus	47 ± 7 mm

Note: Data are presented as count (%) or mean ± standard deviation.

Abbreviations: AF, atrial fibrillation; AV, aortic valve; CAD, coronary artery disease; COPD, chronic obstructive pulmonary disease; EF, ejection fraction; EuroSCORE II, European System for cardiac Operative Risk Evaluation II; PVD, peripheral vascular disease.

TABLE 2 Intraoperative data

Variable	N = 25
Surgical approach	
• Mini-thoracotomy	20 (80)
• Median sternotomy	5 (20)
Cross-clamp time (min)	60.96 ± 11
Cardiopulmonary bypass time (min)	95 ± 16
Ring size (mm), median (Q1–Q3)	34 (32–38)
Number of chordae implanted, median (Q1–Q3)	2 (1–4)
Concomitant aortic valve replacement (bioprosthesis)	3 (12)
Concomitant CABG	2 (8)
Concomitant atrial fibrillation ablation	6 (24)
Conversion to sternotomy	0 (0)
Grade of mitral regurgitation (end of procedure)	
• 0	23 (92)
• 1	2 (8)
• 2+	0 (0)

Note: Data are presented as count (%) or mean ± standard deviation, unless otherwise noted.

Abbreviations: CABG, coronary artery bypass grafting; Q1–Q3, lower quartile-upper quartile.

in-hospital stay was 9 ± 2 days. Postoperative outcomes are presented in Table 3.

3.1 | Follow-up

Completeness of follow-up was 100%. No patients died during the follow-up and there were no adverse cerebrovascular events. A total of 22 (88%) patients were in NYHA class I, and 3 (12%) were in NYHA

class II. The majority of patients (21, 84%) had no residual MR, while 4 (16%) had trace MR. No patients had moderate or severe MR. The coaptation length was 11 ± 1 mm (Figure 3). Follow-up mean ejection fraction was 50 ± 5%. Follow-up results are summarized in Table 4.

4 | DISCUSSION

Artificial chordae have become an essential component of the surgeon's armamentarium for MVr as they allow improved leaflet coaptation and use of larger annuloplasty rings compared to resection techniques.[11]

TABLE 3 Postoperative outcomes

Variable	N = 25
30-Day mortality	0 (0%)
De novo atrial fibrillation	5 (20%)
Acute renal failure	0 (0%)
Cerebrovascular accident	0 (0%)
Re-exploration for bleeding	0 (0%)
Respiratory failure or lung complication[a]	1 (4%)
Need for inotropic support[b]	1 (4%)
Mini-thoracotomy wound infection	0 (0%)
Groin complication	0 (0%)
ICU stay (days)	3 ± 1
Total length of stay (days)	9 ± 2

Note: Data are presented as count (%) or mean ± standard deviation.
Abbreviation: ICU, intensive care unit.
[a]Respiratory failure includes prolonged mechanical ventilation time (>24 h), need for reintubation, and pneumonia; lung complications include persistent airspace or pneumothorax and significant pleural effusion.
[b]Defined as the use of adrenaline and/or dobutamine. Q1–Q3: lower quartile-upper quartile.

However, the correct measurement of the length of artificial chordae is key to achieve mitral valve competence and a durable result.

The most common method of chordal sizing relies on saline inflation of the left ventricle to achieve leaflet apposition. Once this is established, a standard annuloplasty ring is implanted and the neo-chordal sutures are tied.[6,12–15]

Besides the saline inflation method, multiple other techniques have been described for chordal length assessment. Calafiore proposed to calculate the correct length of neo-chordae by subtracting the length of the elongated native chord measured intraoperatively with a ruler from the distance between the plane of the mitral annulus and the edge of the prolapsing mitral leaflet obtained during preoperative transesophageal echocardiography.[16] Mandegar[17] and colleagues suggested an alternative preoperative echocardiographic method consisting of drawing a line between the base of the anterior and posterior mitral leaflets (mitral annulus plane) and calculating the distance between the head of the posterior papillary muscle and the coaptation line. Similarly, Pitisis et al.[18] described an echocardiographic measurement method in which the distance between the top of the fibrous body of the papillary muscle and the lowest point of coaptation between the mitral leaflets was used to determine the appropriate length of neo-chordae.

Duran and Pekar proposed an intraoperative method based on the placement of a temporary Alfieri stitch to align mitral valve leaflets and then subsequently tie a single or multiple neo-chordae with the height of the leaflets opposed by the Alfieri stitch as a guide.[19] A variant of this technique relies on a temporary Alfieri stitch to tie down neo-chordae after filling the left ventricle with saline.[20]

Others have proposed methods based on intraoperative caliper measurements.[21–23] von Oppell used a Vernier caliper with a premeasured length of the neo-chord obtained intraoperatively with a ruler, Doi and Sunazawa proposed a similar approach that included (I) echocardiographic measurement of the distance between the papillary muscle and the free edge of the posterior leaflet opposing the anterior prolapsed portion, (II) intraoperative sizing of the same distance with a caliper, (III)

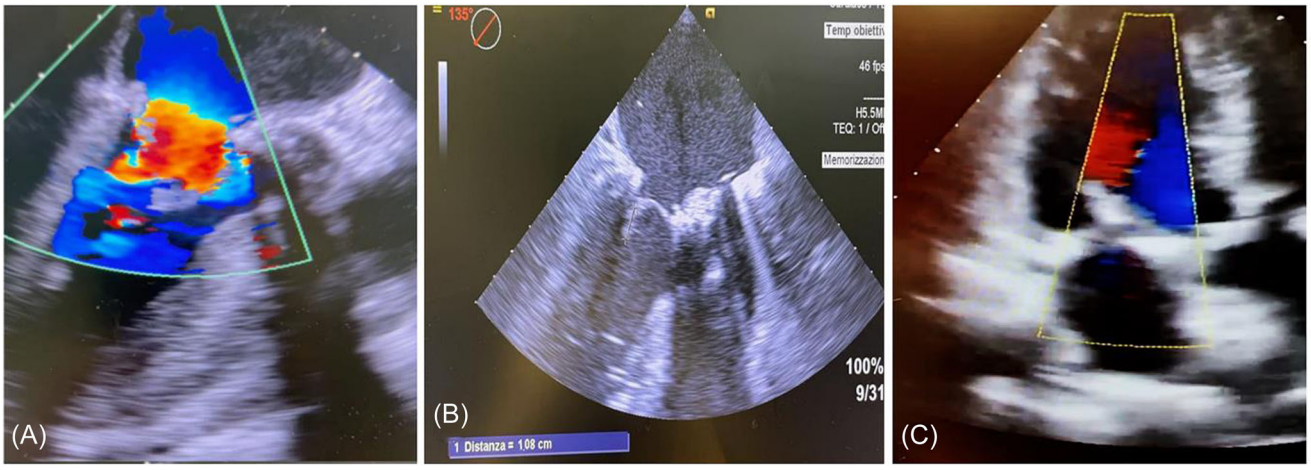

FIGURE 3 (A, B) Postoperative echocardiographic control (midesophageal long axis). (C) 1 year echocardiographic control (apical two-chamber view)

TABLE 4 Follow-up results

Variable	N = 25
Cerebrovascular accident	0 (0)
Pulmonary pressure (mmHg)	43.3 ± 8.3
LVEF (%)	50 ± 5
Grade of MR	
• 0	21 (84)
• 1	4 (16)
• 2+	0 (0)
NYHA class	
• I	22 (88)
• II	3 (12)
• III/IV	0 (0)
Coaptation length ≥10 mm	25 (100)

Note: Data are presented as count (%) or mean ± standard deviation.
Abbreviations: LVEF, left ventricular ejection fraction; MR, mitral regurgitation; NYHA, New York Heart Association.

chordal placement, and (IV) chordal adjustment obtained inserting the premeasured caliper in the loop. Shaikhrezai and Brackenbury[23] described a device which can simultaneously gauge the distance between the papillary muscle and the mitral leaflet while providing a secure platform to tie chordal sutures to the correct length and tension.

Last, in the mid-2000s, two techniques allowing intraoperative adjustment of the length of artificial chordae were reported.[24,25] The method described by Rankin et al.[24] involves loosening or tightening a slipknot to the two ends of a chord and lightly holding it in place with a clip that can be removed if the valve is not competent on saline test. Maselli[25] and colleagues proposed a more elaborate adjusting system that allows chordal length changes by loosening the loop of the leaflet component of the neo-chordae and repositioning it below the desired knot of the papillary component to achieve optimal valve competence.

Our technique is intuitive and easy to perform and relies only on the creation of a temporary guide for neo-chordal attachment between the anterior and the posterior annulus corresponding to the diseased segment. In this regard, the annulus was chosen as the intracardiac landmark for the placement of the guide because of its stability during cardioplegic arrest, unlike the surrounding structures of the mitral valve apparatus. Our approach is simpler than previously described methods, with no preoperative echocardiographic or intraoperative measurement required and no need for ventricular filling, Alfieri stitch or caliper measurements.

5 | CONCLUSION

In conclusion, we have described a promising technique to define the appropriate length of neo-chordae for MVr. Our initial data are promising, showing excellent success rate and good stability of the repair at 1-year follow-up. Although our outcomes are relative to patients with anterior leaflet disease, this new method is currently being tested in patients with posterior leaflet disease and initial results are encouraging. However, long-term follow-up is needed to prove the durability of this technique.

AUTHOR CONTRIBUTIONS

Nasso Giuseppe and Nicola Di Bari: substantial contribution to the conception or design of the work AND substantial contribution to the acquisition, analysis or interpretation of data for the work AND final approval of the version to be published. **Raffaele Bonifazi**: substantial contributions to the acquisition, analysis or interpretation of data for the work. **Giuseppe Santarpino, Marco Moscarelli, Ignazio Condello, and Felice Agrò**: drafting the work or revising it critically for important intellectual content. **Giovanni Jr Soletti, Stephanie Mick, and Domenico Paparella**: substantial contribution to the conception or design of the work. **Mario Gaudino and Giuseppe Speziale**: agreement to be accountable for his contributions of the work in ensuring that questions related to the accuracy or integrity of the work are appropriately investigated and resolved.

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CONFLICTS OF INTEREST

The authors declare no conflicts of interest.

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