Comparison of the Outcomes of Modified Artificial Chordae Technique for Mitral Regurgitation through Right Minithoracotomy or Median Sternotomy

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Abstract

Background: Right minithoracotomy (RM) has been proven to be a safe and effective approach for mitral valve surgery, but the differences of artificial chordae technique between RM and median sternotomy (MS) were seldom reported. Here, we compared the outcomes of modified artificial chordae technique for mitral regurgitation (MR) through RM or MS approaches.

Methods: One hundred and eighteen consecutive adult patients who received mitral valve repair with artificial chordae and annuloplasty for MR through RM ($n = 58$) or MS ($n = 60$) from January 2006 to January 2015 were analyzed.

Results: All of the selected patients underwent mitral valve repair successfully without any complication during the surgery. There was no significant difference between RM group and MS group in cardiopulmonary bypass time, aortic cross-clamp time, and early postoperative complications. However, compared with the MS group, the RM group had shorter hospital stay and faster surgical recovery. At a mean follow-up of 44.8 ± 25.0 months, the freedom from more than moderate MR was $93.9\% \pm 3.5\%$ in RM group and $94.8\% \pm 2.9\%$ in MS group at 3 years postoperatively. Log-rank test showed that there was no significant difference in the freedom from recurrent significant MR between the two groups ($\chi^2 = 0.247$, $P = 0.619$). Multivariate analysis revealed that the presence of mild MR at discharge was the independent risk factor for the recurrent significant MR.

Conclusion: Right minithoracotomy can achieve the similar therapeutic effects with MS for the patients who received modified artificial chordae technique for treating MR.

Key words: Artificial Chordae; Minimally Invasive Surgery; Mitral Regurgitation; Mitral Valve Repair

INTRODUCTION

Mitral valve repair with artificial chordae is considered as a good choice for correcting mitral regurgitation (MR) caused by mitral valve prolapse due to chordal elongation or rupture.[1,2] The polytetrafluoroethylene (PTFE) suture has been applied as artificial chordae in large series with good outcomes.[3-7] However, artificial chordae remains challenging for cardiac surgeon because of the difficulties in adjusting the accurate length of artificial chordae and tying the knot at the intended length. Nowadays, various techniques for making artificial chordae adjustment and tying knot have been reported, but the results are controversial.[8-13] To overcome these two difficulties and improve the surgical outcomes, we applied a modified artificial chordae technique with PTFE suture in mitral valve repair for MR since 2006.

Recently, the less invasive approach using right minithoracotomy (RM) has been applied increasingly, which has been proved to be a safe procedure with

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satisfactory outcomes in the mitral valve surgery.[14-17] However, the surgical exposure of RM for the operation of artificial chordae is not as good as that of traditional median sternotomy (MS), which may affect the effect of mitral valve repair with artificial chordae. Therefore, the aims of the present study were (1) to evaluate the early and long-term results of the modified artificial chordae technique and (2) to compare the outcomes of modified artificial chordae technique for treating MR through RM or MS approaches.

METHODS

The study protocol was approved by the Institutional Review Board in Xinhua Hospital, School of Medicine, Shanghai Jiao Tong University, and informed consent was obtained from all patients. From January 2006 to January 2015, a total of 336 consecutive adult patients with MR underwent mitral valvuloplasty (MVP) in our hospital. Among them, 118 patients underwent MVP with PTFE artificial chordae implantation through either RM ($n = 58$) or MS ($n = 60$). There were 71 males and 47 females. Patients aged from 23 to 72 years (mean 57.3 ± 9.8 years). All patients underwent preoperative transesophageal echocardiography (TEE) to determine the mechanism of MR and evaluate the degree of MR. The degree of MR was graded based on the maximum length and width of the abnormal jet relative to the left atrium: none (0), trivial (+), mild (++), moderate (+++), or severe (++++). All 118 patients had severe MR and mitral valve prolapse due to chordal elongation or rupture. Valve lesions were posterior in 70 cases (59.3%), anterior in 32 cases (27.1%), and both anterior and posterior in 16 cases (13.6%). The preoperative associated diseases within these 118 patients are commonly involved hypertension (18, 15.3%), diabetes mellitus (8, 6.8%), cerebrovascular disease (6, 5.1%), endocarditis (4, 3.4%), renal dysfunction (4, 3.4%), and chronic obstructive pulmonary disease (3, 2.5%). Thirty-two (27.1%) patients had more than mild tricuspid regurgitation (TR) preoperatively. Preoperative left ventricular ejection fraction ranged from 36% to 62% (mean $53.1\% \pm 4.6\%$). Preoperative left ventricular end-diastolic diameter (LVEDD) ranged from 45 mm to 69 mm (mean 57.5 ± 6.8 mm). Twenty-one patients (17.8%) were in the New York Heart Association (NYHA) functional Class I, 58 patients (49.2%) were in NYHA functional Class II, 34 patients (28.8%) were in NYHA functional Class III, and 5 patients (4.2%) were in NYHA functional Class IV. Patients with coronary artery disease and atrial fibrillation were excluded from the study.

Surgical techniques

The surgical procedure was performed with cardiopulmonary bypass (CPB) under moderate systemic hypothermia through either RM or MS. Intraoperative TEE was routinely used to monitor the cardiac function, evaluate the mechanism of valve pathology and de-air the heart after the surgery. In the RM group, the patient was positioned supine with the right side elevated 30°. A minimal right anterolateral thoracotomy was performed through the fourth intercostal space. Peripheral CPB was established through the femoral artery and femoral vein or right jugular vein. In the MS group, traditional CPB with aortic cannulation and vena cava return was established after a standard sternotomy.

After ascending aortic cross-clamping (ACC), mitral valve repair with artificial chordae and mitral annuloplasty were performed as following [Figure 1]: mitral valve was approached through left atriotomy or atrial septum incision. First, mitral valve was examined carefully, especially the place of chordal elongation or rupture. After the evaluation of valve pathology, mitral valve repair was performed. A double-armed PTFE suture was fixed at the papillary muscle head corresponding to the prolapsed area using "U-" shaped suture without pledget. Then, the needles were passed through the free edge of the prolapsing portion (3–5 mm from the margin) twice from the ventricular side to the atrial side [Figure 1a and 1b]. If the number of elongated or ruptured chordae was more than one or the prolapsed area was wide, 2 or 3 PTFE sutures would be implanted. Then, mitral annuloplasty was performed using an appropriate C-ring mitral prosthetics around the posterior leaflet [Figure 1c]. Leaflet cleft was repaired by interrupted simple prolene sutures. After that, the length of artificial chordae was adjusted by injecting cold saline into the left ventricle through mitral valve orifice until perfect coaptation of the mitral leaflet was obtained [Figure 1a]. Both needles were passed through the edge of the prolapsing scallop one more time to prevent chordae moving when tying the knot. Finally, both arms of the artificial chordae were tied together [Figure 1c]. Before closing the left atrium, valve competency was tested again by injecting cold saline [Figure 1d]. Segmental resection of posterior leaflet will be applied to patients with significant posterior leaflet prolapse. If the result of repair was not satisfactory, edge to edge technique would also be used.
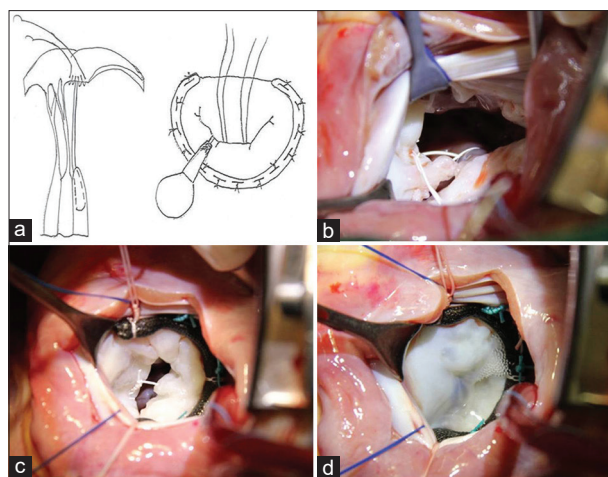

Figure 1: (a) Modified artificial chordae technique; (b) placing the suture on the head of the papillary muscle and the prolapsing portion of mitral leaflet; (c) tying and cutting the knot after length adjustment; (d) valve competency was tested again by injecting cold saline into the left ventricle after mitral valvuloplasty.

Concomitant TR was treated simultaneously during the surgery. The results of mitral valve repair were evaluated by TEE performed during the operation. If the residual regurgitation was greater than mild MR, redo mitral valve repair or replacement was necessary.

Postoperative anticoagulation and follow-up
To prevent thrombosis after surgery, warfarin was administered to patients for 6 months (international normalized ratio 2.0–3.0). Patients' in-hospital data and follow-up data were collected from clinical and outpatient clinic files. Transthoracic echocardiography (TTE) was performed at 6 and 12 months postoperatively and every year thereafter.

Statistical analysis
The statistical analysis was performed with the SPSS version 19.0 software program (SPSS Inc., Chicago, IL, USA). Categorical variables were expressed as frequencies and proportions and are compared using the Chi-square test or Fisher's exact test. Continuous variables were presented as mean ± standard deviations (SDs) and were compared using the Student's unpaired t-test. The freedom from more than moderate MR after MVP was determined by Kaplan-Meier methods and compared using the log-rank test. The Cox proportional hazards regression method was used to assess the relationship of clinical characteristics to the recurrence of more than moderate MR during follow-up. Results were considered to be statistically significant if $P < 0.05$.

RESULTS
All patients successfully underwent mitral valve repair with artificial chordae and annuloplasty through RM or MS. No patients need to convert to sternotomy in the RM group. Baseline characteristics of both groups are shown in Table 1. There were no significant differences in the baseline characteristics between RM group and MS group. Average 2.2 ± 0.7 (range from 1 to 3) PTFE artificial chordae were implanted per patient. Each patient had a C-ring mitral prosthetics implanted. Mean ring size was 29.2 ± 1.8 mm (range from 26 to 32 mm). Intraoperative TEE showed no MR in 79 cases (66.9%), trivial MR in 32 cases (27.1%), and mild MR in 7 cases (5.9%). No patients required mitral valve replacement or redo-repair during the surgery. There were no significant differences in CPB time, ACC time, and early postoperative complications between the two groups [Table 2]. However, compared with the MS group, the RM group had shorter postoperative ventilation time, hospital stay, and better cosmetic outcomes [Table 2]. There was no early death in both groups. At discharge, none or trivial MR was in 114 cases, and mild MR was in 4 cases [Table 2]. Postoperative TTE showed that LVEDD was significantly reduced at postoperative 6 months compared with the preoperative values (51.6 ± 4.4 mm vs. 57.5 ± 6.8 mm, $t = -11.486$, $P < 0.001$).

At a mean follow-up of 44.8 ± 25.0 months, complete follow-up data were available in 109 patients (109/118,

Table 1: Baseline characteristics in both RM and MS groups

Variables	RM group	MS group	Statistical value	P
Number of patients	58	60	/	/
Age (years)	55.8 ± 10.2	58.9 ± 9.1	−1.744*	0.084
Female, n (%)	26 (44.8)	21 (35.0)	1.188†	0.276
Valve lesion, n (%)				
Posterior	37 (63.8)	33 (55.0)	0.945†	0.331
Anterior	14 (24.1)	18 (30.0)	0.513†	0.474
Posterior and anterior	7 (12.1)	9 (15.0)	0.216†	0.642
LVEDD (mm)	56.2 ± 5.7	57.1 ± 7.1	−0.750*	0.455
LVEF (%)	53.4 ± 3.5	52.7 ± 5.5	0.867*	0.388
Mitral regurgitation, n				
Severe (++++)	58	60	/	/
Tricuspid regurgitation, n (%)				
Mild (++)	8 (13.8)	10 (16.7)	0.188†	0.664
Moderate (+++)	4 (6.9)	5 (8.3)	/	1.000
Severe (++++)	1 (1.7)	2 (3.3)	/	1.000
Hypertension, n (%)	10 (17.2)	8 (13.3)	0.348†	0.555
Diabetes mellitus, n (%)	5 (8.6)	3 (5.0)	/	0.487
Cerebrovascular disease, n (%)	2 (3.4)	4 (6.7)	/	0.680
Endocarditis, n (%)	2 (3.4)	2 (3.3)	/	1.000
Renal dysfunction, n (%)	2 (3.4)	2 (3.3)	/	1.000
COPD, n (%)	1 (1.7)	2 (3.3)	/	1.000
Cardiac function (NYHA), n (%)				
I	12 (20.7)	9 (15.0)	0.653†	0.419
II	32 (55.2)	26 (43.3)	1.654†	0.198
III	13 (22.4)	21 (35.0)	2.278†	0.131
IV	1 (1.7)	4 (6.7)	/	0.365

Data are presented as n (%) or mean ± standard deviation. *t value; †χ^2 value. COPD: Chronic obstructive pulmonary disease; LVEDD: Left ventricular end-diastolic diameter; LVEF: Left ventricular ejection Fraction; NYHA: New York Heart Association; /: Not applicable; RM: Right minithoracotomy; MS: Median sternotomy.

92.4%). During the follow-up, one patient died from heart failure. None or trivial MR was in 89 cases (81.7%), mild MR was in 12 cases (11.0%), moderate MR was in 4 cases (3.7%), and severe MR was in 4 cases (3.7%). One patient with recurrent severe MR had mitral valve infective endocarditis. Four patients with recurrent severe MR received late mitral valve replacement and one patient died from multiple organ failure. For 107 survival patients with complete follow-up, 92 patients (86.0%) were in NYHA functional Class I, 13 patients (12.1%) were in NYHA functional Class II, and 2 patients (1.87%) were in NYHA functional Class III.

For the overall group, the freedom from more than moderate MR at 1, 3, 5 years postoperatively was 97.5% ± 1.5%, 94.3% ± 2.3%, and 90.9% ± 3.3%, respectively. The freedom from more than moderate MR at 1 year postoperatively was 96.6% ± 2.4% in RM group and 98.3% ± 1.7% in MS group. The freedom from more than moderate MR at 3 years postoperatively was 93.9% ± 3.5% in RM group and

Table 2: Perioperative results in both RM and MS groups

Variables	RM group	MS group	t	P
Number of patients	58	60	/	/
Number of artificial chordae	2.1 ± 0.7	2.3 ± 0.8	−1.363	0.176
CPB time (min)	85.7 ± 9.5	83.9 ± 9.9	1.047	0.297
ACC time (min)	61.9 ± 9.3	60.3 ± 9.0	0.938	0.350
Ring size (mm)	29.1 ± 1.9	29.4 ± 1.8	−0.780	0.437
Postoperative ventilation time (h)	9.9 ± 4.3	15.9 ± 4.7	−7.221	<0.001
Postoperative hospital stay (days)	7.4 ± 1.2	9.2 ± 1.7	−6.638	<0.001
Early postoperative complications, *n* (%)				
Low cardiac output syndrome	1 (1.7)	2 (3.3)	/	1.000
New onset atrial fibrillation	2 (3.4)	2 (3.3)	/	1.000
Acute renal dysfunction	1 (1.7)	1 (1.7)	/	1.000
Reoperation for bleeding	0 (0)	1 (1.7)	/	1.000
MR at discharge, *n* (%)				
None or trivial (0 – +)	56 (96.6)	58 (96.7)	/	1.000
Mild (++)	2 (3.4)	2 (3.3)	/	1.000
Moderate (+++)	0 (0)	0 (0)	/	/
Severe (++++)	0 (0)	0 (0)	/	/

Data are presented as *n* (%) or mean ± standard deviation. ACC: Aortic cross-clamp; CPB: Cardiopulmonary bypass; /: Not applicable; RM: Right minithoracotomy; MS: Median sternotomy; MR: Mitral regurgitation.

94.8% ± 2.9% in MS group. The freedom from more than moderate MR at 5 years postoperatively was 90.1% ± 5.0% in RM group and 91.8% ± 4.1% in MS group. Log-rank test showed that there was no significant difference between the two groups regarding the freedom from more than moderate MR during follow-up ($\chi^2 = 0.247$, $P = 0.619$) [Figure 2]. Cox regression analysis showed that the presence of mild MR at discharge was the independent risk factor for the recurrence of more than moderate MR during follow-up [hazard ratio 3.329, 95% confidence interval 0.637–10.809; Table 3]. However, both anterior and posterior leaflet prolapse, preoperative LVEDD ≥65 mm, and preoperative significant TR were not an independent risk factor for recurrent significant MR.

DISCUSSION

MVP has become the first treatment choice for patients with MR, and various techniques have been reported in the recent years. Among them, mitral valve repair with artificial chordae is considered to be the best method to correct MR due to chordal elongation or rupture.[1,2] Since chordal replacement with PTFE suture was introduced, it has been widely adopted and the outcomes are satisfactory.[3-7,18] However, there are still two major problems affecting the results of artificial chordal technique for treating MR. One is adjusting the accurate length of artificial chordate, and the other is tying the knot at the intended length. At present, several techniques have been described to overcome these two problems.[2,10,19] Cagli[20] described a technique of making chordal loops using Hegar dilators and represented tailoring of this technique to the preparation of two connected sets of chordal loops of different predetermined lengths for repair of bileaflet prolapse of opposing segments. Chang and Kao[21] reported another method using a slit plastic tube for stenting
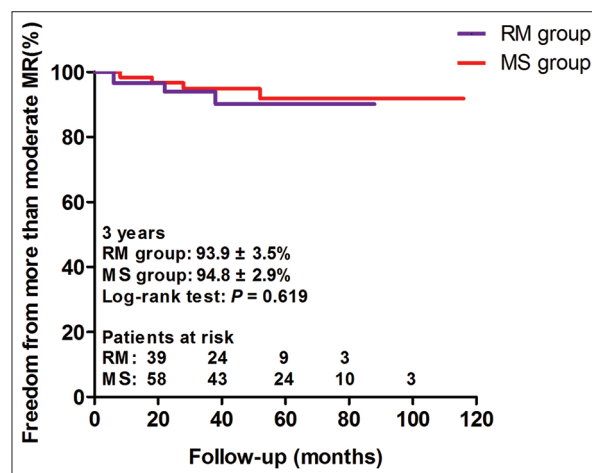

Figure 2: The freedom from more than moderate mitral regurgitation after mitral valvuloplasty of the two groups. RM: Right minithoracotomy; MS: Median sternotomy; MR: Mitral regurgitation.

the artificial chordae at the intended length. In addition, Moorjani *et al.*[22] developed a single-loop technique, which provided a simple, reproducible method for adjusting neochordal length to ensure valvular competency. However, some techniques are unfit for minimally invasive mitral valve repair because of the complicated practical operation. Determining the correct length of artificial chordate and tying the knot at the intended length remain problematic during mitral valve repair through RM.

In 1991, David *et al.* [3,23] reported a simple artificial chordae technique with satisfactory outcomes: a double-armed suture was passed twice through the fibrous portion of the papillary muscle head and tied down. Then, each arm of the suture was passed through the free margin of the leaflet. After the length of the two arms was adjusted, the ends were tied together on the ventricular side of the leaflet. According to David's

Table 3: Cox regression analysis

Variables	HR	95% CI	P
Preoperative LVEDD ≥65 mm	1.545	0.636–5.061	0.352
Preoperative significant TR	0.519	0.237–1.134	0.100
Both anterior and posterior leaflet prolapse	1.086	0.089–4.812	0.823
Mild MR at discharge	3.329	0.637–10.809	0.027

CI: Confidence interval; *HR*: Hazard ratio; LVEDD: Left ventricular end-diastolic diameter; TR: Tricuspid regurgitation; MR: Mitral regurgitation.

method, we modified the technique and applied it to correct mitral valve prolapse since 2006. There are several precautions in our modified technique as following: (1) Placing the suture on the head of the papillary muscle and the prolapsing portion of mitral leaflet was performed before the remodeling annuloplasty, but adjusting the length of chordae and tying the knot are performed after annuloplasty. One reason is that the exposure of papillary muscle before annuloplasty is better than that after annuloplasty.[10] Another reason is that subsequent annuloplasty will affect the correct length of chordae, if length adjustment is earlier than remodeling annuloplasty. (2) The PTFE suture was fixed at the papillary muscle head using "U-" shaped suture without pledget. The PTFE suture could be pulled easily without the pledget, which is beneficial to adjust the length of artificial chordae. (3) Each PTFE artificial chordae was sutured in the edge of valve leaflet for twice at the time of adjusting chordae length, but three times at the point of tying the knot. Only double-layer suturing is convenient for surgeon to slide and pull the suture, which is beneficial for length adjustment. Whereas chordae could be fixed more firmly with three times suturing so that the artificial chordae was not easy to slide or shift when tying the knot. (4) Because most patients had annulus dilatation, especially in the posterior annulus, C-ring mitral prosthetics was implanted for each patient in the present study. At present, several studies have shown the early or long-term outcomes of mitral valve repair, but most studies reported the results as cumulative data without the specificity of the technique of artificial chordae.[24,25] In the present study, we described the modified technique of artificial chordae and reported the early and long-term outcomes. In our series, we performed the modified artificial chordae technique in 118 patients with severe MR and mitral valve prolapse. Intraoperative TEE showed no MR in 79 cases (66.9%), trivial MR in 32 cases (27.1%), and mild MR in 7 cases (5.9%). No patients required mitral valve replacement or redo-repair during the surgery. At discharge, TTE showed that only four patients had mild MR. At a mean follow-up of 44.8 ± 25.0 months, the freedom from more than moderate MR at 1, 3, 5 years postoperatively was 97.5% ± 1.5%, 94.3% ± 2.3%, and 90.9% ± 3.3% for the overall group, respectively. The early and mid-term outcomes of MVP with our modified method are satisfactory in our institute, and these are comparable to those reported in literature.[26-28] Therefore, we concluded that our modified technique was a simple, safe, and effective for correcting severe MR associate with mitral valve prolapse.

RM has been proven to be a safe and effective approach for mitral valve surgery.[14-17] Currently, a few of studies[29-31] have reported the outcomes of artificial chordae technique for MR through RM, but the differences of artificial chordae technique between RM and MS were seldom reported. In our series, 118 adult patients received mitral valve repair with artificial chordae and annuloplasty for MR. Among them, 58 patients received MVP through RM, and MVP was performed through MS in other sixty cases. There was no significant difference between the two groups with regard to the freedom from more than moderate MR. In addition, there were no significant differences in CPB time, ACC time, and early postoperative complications between the two groups; however, the RM group had shorter hospital stay and ventilation time compared with the MS group. Therefore, we concluded that RM could achieve the similar therapeutic effects with MS for the patient who received modified artificial chordae technique for treating MR. Different approach of thoracotomy was not a risk factor for the recurrent significant MR.

Previous studies have shown that MVP without annuloplasty ring, more than mild MR at discharge, preoperative significant TR, preoperative left ventricle dilation with LVEDD >65 mm, anterior leaflet prolapse, or both anterior and posterior leaflet prolapse may be the risk factors for recurrent significant MR.[26,32-36] In our institute, annuloplasty ring was applied as a standard technique for MV repair with artificial chordae, which may be one important factor responsible for the satisfactory outcomes. According to the Cox regression analysis, the presence of mild MR at discharge was the independent risk factor for the recurrent significant MR at follow-up in our study. To avoid the presence of mild MR at discharge, reasonable perioperative treatment is the most important cornerstone that including: (1) individualized surgical technique is the key to successful surgical therapy. Several techniques were sometimes used in a single patient. (2) Intraoperative TEE is mandatory for all patients. If the residual MR was greater than mild, redo mitral valve repair or replacement would be necessary. However, redo mitral valve surgery would not be performed for patients with residual mild MR during the surgery in operation room because the second run of CPB would be more life-threatening than the mild MR. Besides, mild MR might be relieved in the early postoperation after medical therapy in some patients. (3) Reduced postoperative cardiac preload is also one important cornerstone of successful therapy for patients with MVP, which could avoid the tear of leaflet or chordae induced by abnormal heart contraction. Therefore, diuretics and vasodilators therapy is recommended to these patients in the early postoperative. In this study, intraoperative TEE showed that seven patients had residual mild MR on leaving the operation room. After medical therapy, four patients still had mild MR at discharge. However, three of these four patients developed to significant MR during the follow-up. Further studies are necessary

to investigate the mechanism of recurrent significant MR related to residual mild MR at discharge.

There are few limitations in this study. First, this was a retrospective analysis and thus had some inherent limitations. Second, our series were small size. Whether our method had a satisfactory recovery, it was still be confirmed by more cases. Third, most patients preferred to choose mitral valve replacement rather than MVP in China because of personal economic problems. Some MR patients with severe mitral valve lesions underwent mitral valve replacement directly without trying to receive MVP in our institute, which might also have a good effect on our outcomes.

In conclusion, RM can achieve the similar therapeutic effects with MS for the patients who received modified artificial chordae method for treating MR. Individualized reasonable surgical technique is the key to successful surgical therapy.

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Conflicts of interest
There are no conflicts of interest.

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