Chordal Translocation: Secondary Chordal Cutting in Conjunction with Artificial Chordae for Preserving Valvular-Ventricular Interaction in the Treatment of Functional Mitral Regurgitation

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Background and aim of the study: **Functional mitral regurgitation (FMR) with leaflet tethering is a serious complication related to dilated cardiomyopathy. Although FMR with mitral leaflet tethering can be improved by secondary chordal cutting, the technique may compromise valvular-ventricular interaction. The aim of chordal translocation (CT) is to maintain valvular-ventricular interaction.**
Methods: **An initial successful mitral valve repair with CT was performed on a 55-year-old patient with FMR. Following secondary chordal cutting, artificial chordae were sutured to the tip of each papillary muscle, from where the secondary chordae originated. The artificial chordae were passed through the mid-septal annulus and fixed on the side of the left atrium. The force direction generated by the artificial chordae was very similar to the natural stress line on the anterior mitral leaflet. In a subsequent clinical series, CT was performed on 13 FMR patients.**
Results and Conclusion: **The study results indicated that CT, in conjunction with secondary chordal cutting, might represent a promising treatment for preserving valvular-ventricular interaction in FMR patients.**

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Functional mitral regurgitation (FMR), a serious complication which is related to dilated cardiomyopathy, is associated with increased mortality, irrespective of whether an underlying left ventricular dysfunction is present. FMR is caused by mitral annular dilatation and mitral leaflet tethering that occurs due to the lateral displacement of the posterior/anterior papillary muscles (1). Although the standard procedure used to treat FMR is mitral annuloplasty using an undersized ring, this technique is not efficient for treating FMR with significant mitral leaflet tethering (2,3).

Recently, a variety of techniques involving the internal repositioning of the papillary muscles have been reported for repairing the lateral displacement of the latter. For example, Kron et al. demonstrated the efficiency of internal papillary muscle repositioning by pulling the posterior papillary muscle towards the right fibrous trigone in the mitral annulus, without the need for secondary chordal cutting (4). Likewise, Langer et al. demonstrated the efficacy of this method for treating acute ischemic mitral regurgitation (IMR) in an ovine model (5), and clinically evaluated the efficacy of direct internal repositioning of the posterior papillary muscle towards the mid-septal annulus (saddle horn), via the aortic approach (6). These preliminary studies were based on the hypothesis of Tibayan et al. (1), that correction of the distance between the saddle horn and the papillary muscle tips plays a key role in improving the FMR.

Secondary chordal cutting, whereby the secondary chordae are severed, is a simple method used to repair severe tethering. However, as the secondary chordae maintain mitral valvular-ventricular continuity, they play an important role in maintaining left ventricular performance (7). Consequently, this method may aggravate left ventricular dysfunction.

Recently, the present authors have developed a chordal translocation (CT) technique that restores the valvular-ventricular continuity following secondary chordal cutting, by using a canine model. In this way, CT helps to overcoming the shortcomings of secondary chordal cutting (8,9). The application of CT for FMR treatment in a clinical setting formed the basis of the present study.

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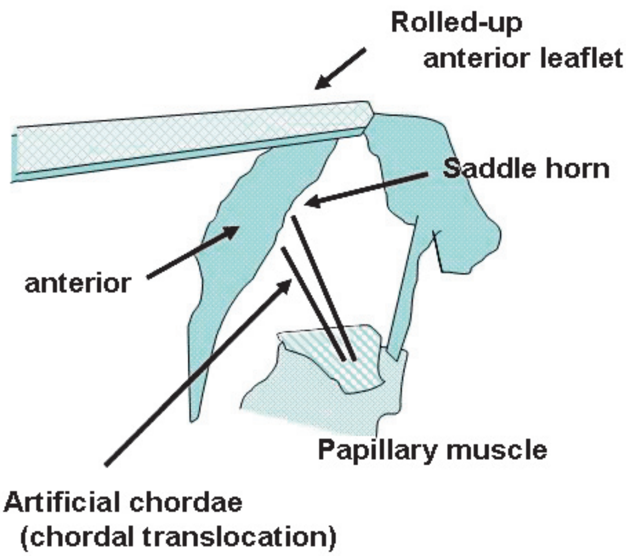

Figure 1: An intraoperative view through right-sided atriotomy. The artificial chordae are placed by anchoring in each papillary muscle tip, and are then passed through the saddle horn.

Clinical material and methods

Preliminary study

A 55-year-old man presenting with ischemic cardiomyopathy associated with FMR was admitted to the authors' institution. Seven years previously, he had undergone coronary artery bypass grafting (CABG) (left internal thoracic artery to left descending artery, aorta to first obtuse marginal branch by saphenous vein) for chronic myocardial infarction of the anterior and lateral walls. However, even after the surgery, the symptoms of both cardiomyopathy and heart failure had progressively worsened. Echocardiography revealed a left ventricular ejection fraction (LVEF) of 27% with moderate mitral regurgitation (MR), and severe hypokinesis of the anterior and lateral walls. The 'tethering height' - that is, the distance between the leaflet coaptation site and the annular plane - was also measured. A characteristic distraction was observed on the anterior mitral leaflet, which was tethered by the secondary chordae (tethering height 10 mm) to form a bend, thereby reducing the area of the coapting surface. Preoperative coronary angiography revealed no progression of coronary arterial stenosis or restenosis at the site of the CABG.

At surgery, a median sternotomy was performed, followed by mitral valve repair and CABG. The right internal thoracic artery (RITA) and gastroepiploic artery (GEA) were harvested. During cardiopulmonary bypass (CPB) with cardiac arrest, the mitral valve was exposed via a right-sided left atriotomy, and

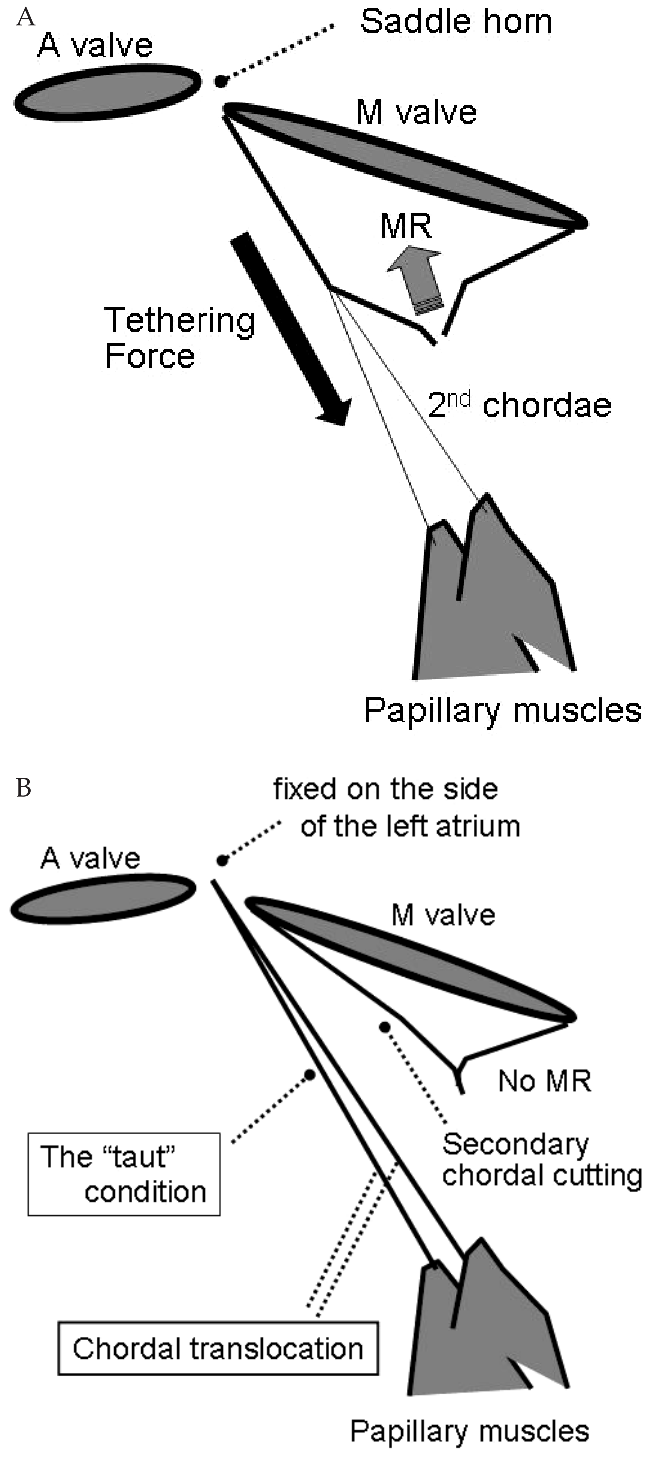

Figure 2: Schematic representation of chordal translocation with chordal cutting. A) Mitral regurgitation arises from tethering of the anterior leaflet. B) Chordal translocation was carried out after secondary chordal cutting. A valve: Aortic valve; M valve: Mitral valve.

the tips of each papillary muscle and the anterior mitral annulus were examined. Although both mitral leaflets appeared normal, the anterior mitral leaflet

Table I: Preoperative, intraoperative and postoperative data of the clinical study patients.

Preoperative factors						Surgery			Postoperative factors			
Age/ gender	Re-do surgery	Etiology	LVEF (%)	Tethering height (mm)	MR grade[#]	CPB (min)	ACT (min)	Ring size (mm)	LVEF (%)	Tethering height (mm)	MR grade[#]	Outcome
53/M	No	ICM	30	11	3	158	123	25	40	4	0	Alive
52/M	No	DCM	10	12	3	253	45	26	20	3	1	Dead[*]
62/F	No	DCM	23	11	3	241	135	24	56	5	0	Alive
63/M	No	DCM	25	9	3	181	126	25	39	4	1	Dead[+]
59/M	No	ICM	38	9	2	160	128	24	46	3	1	Alive
75/F	No	DCM	19	11	4	103	81	25	30	3	1	Alive
65/M	No	ICM	20	12	4	258	64	25	35	5	1	Dead[†]
64/M	No	ICM	26	12	2.5	174	139	25	60	3	0	Alive
60/M	No	DCM	9	9	3	218	35	25	25	5	1	Alive
46/M	No	ICM	30	8	2	240	102	25	40	4	0	Alive
81/F	No	DCM	38	9	2.5	132	69	27	71	5	1	Alive
68/F	No	ICM	37	9	3	146	47	25	46	3	1	Dead[§]
55/M	Yes	ICM	27	10	3	270	152	25	41	3	1	Alive

[#]MR grading: 0 = none; 1 = trace; 1.5 = trace-mild; 2 = mild; 2.5 = mild-moderate; 3 = moderate; 3.5 = moderate-severe; 4 = severe.
[*]Heart failure; [+]Sudden death; [†]Ventricular tachycardia; [§]Cerebral vessel aneurysm.
ACT: Aortic cross-clamp time; CPB: Cardiopulmonary bypass time; DCM: Dilated cardiomyopathy; ICM: Ischemic cardiomyopathy; LVEF: Left ventricular ejection fraction; MR: Mitral regurgitation; Ring: Ring size of mitral annuloplasty.

was lifted to identify the secondary chordae beneath it.

Both of the secondary chordae, which exert a force on the body of the anterior mitral leaflet, were severed as secondary chordal cutting. A 5-0 Teflon-pledgeted polytetrafluoroethylene suture was used as an artificial chordae; this was sutured to the tip of each papillary muscle, from where the secondary chordae originated. The artificial chordae were passed through the saddle horn and fixed on the side of the left atrium (Figs. 1 and 2), with care being taken to avoid damage to the aortic cusps. The length of the artificial chordae was adjusted such that excessive tension did not develop at each papillary muscle tip, and the chordae appeared straight with minimum tension (i.e., taut) in the operative field. The distances between the trigones of the mitral annulus were measured using a sizer, and the mitral annuloplasty was performed by using a 25-mm flexible ring and 2-0 Tycron interrupted mattress sutures. Furthermore, CABG (aorta to intermediate branch by RITA free graft, GEA to second obtuse marginal branch via posterolateral branch as a sequence) was performed. After weaning the patient from CPB, intraoperative transesophageal echocardiography confirmed the improvement in MR following tethering of the anterior mitral leaflet.

The patient experienced an uneventful recovery, with postoperative echocardiography revealing trivial MR, an improvement in the leaflet tethering (tethering height 3 mm), no prolapse of the anterior mitral leaflet in spite of secondary chordal cutting, and an improvement in the LVEF (to 42%).

Clinical series

Between September 2004 and August 2006, 13 patients (nine males, four females; mean age 61 ± 9 years) with FMR caused by ischemic or idiopathic cardiomyopathy were treated using the above-described technique. The preoperative and postoperative data of the patients are summarized in Table I. The mean preoperative MR grade, tethering height and LVEF were 2.9 ± 0.7, 10 ± 1.4 mm and 26 ± 14%, respectively. Mitral annuloplasty was performed on all patients by using an undersized flexible or semi-rigid ring (24-27 mm). In addition, CABG (n = 6), tricuspid annuloplasty (n = 6) and surgical ventricular restoration (n = 5) were performed.

There was no operative mortality. Postoperatively, the MR grade was reduced to 0.7 ± 0.4 ($p < 0.001$ versus preoperative value, as determined by the Wilcoxon single-rank test), and the tethering height was markedly decreased to 3.8 ± 0.8 mm ($p < 0.001$ versus preoperative value). The postoperative LVEF was 42 ± 14% ($p < 0.001$ versus preoperative value). Although a suture made at the saddle horn may have caused aortic regurgitation if the non-coronary aortic cusp was involved, this did not occur in any of the 13 cases.

The mean follow up period was 19 months, during which time three patients died due to aneurysm of a cerebral vessel, refractory ventricular arrhythmias, and heart failure despite the absence of MR; the three deaths occurred at six, six and 17 months after surgery, respectively. A fourth patient died suddenly, of unknown cause, at 25 months after surgery. This relatively high rate of late mortality may have been attributed to the fact that, preoperatively, the general condition of the patients was poor, or their cardiac reserve was too small.

Discussion

It is well known that mitral valvular-ventricular interaction is important for maintaining left ventricular systolic function (7). In particular, the secondary chordae - the large chordae that are inserted to the anterior mitral leaflet - play an important role in preserving valvular-ventricular interaction. Although secondary chordal cutting is commonly used to treat FMR, and can also improve mitral valve tethering, it may compromise the valvular-ventricular interaction. In the past, the status of left ventricular systolic function following secondary chordal cutting has been considered controversial. For example, Messas et al. reported that the left ventricular function was maintained following secondary chordal cutting in a normal ovine model (10). In contrast, Rodriguez et al. noted that secondary chordal cutting altered the left ventricular geometry and impaired the left ventricular systolic function (7). Furthermore, He and Jowers indicated that secondary chordal cutting would lead to increased tension in the marginal chordae and might ultimately affect mitral valve function, and thus left ventricular function (11). Therefore, by maintaining valvular-ventricular interaction, the secondary chordae may play an important role in left ventricular systolic function.

The aim of CT is to restore any valvular-ventricular interaction that may have been compromised by secondary chordal cutting. The force direction generated by the artificial chordae in CT is very similar to the natural direction, as indicated by the stress line on the anterior leaflet (which extends from the secondary chordal insertion to the anterior mitral annulus). To date, many studies have focused on the treatment of FMR, but few have considered how to preserve or enhance the left ventricular function. In light of the information provided in the present study, CT might become a preferred modality for treating FMR, as it can ameliorate severe tethering and maintain valvular-ventricular interaction while preventing the development of excessive tension in the papillary muscles (by maintaining a constant distance between the papillary muscles and the mid-septal mitral annulus).

The efficacy and shortcomings of this novel method have been reported previously, using a canine animal model, when it was found that the tension in the artificial chordae should be minimal (i.e., no excessive tension) (8,9). The other internal-repositioning techniques, as described above, might be singularly effective for the treatment of FMR; however, suturing the papillary muscle tip might cause excessive tension in the chordae (12). In order to avoid this situation, the length of the artificial chordae used in CT is adjusted such that they appear straight with minimum tension (i.e., taut) in the operative field. Experience gathered from experimental series has suggested that, if the chordae experience excessive tension, then the systolic function will not improve and the diastolic function will be impaired; this may in time lead to ventricular arrhythmias or papillary muscle rupture (9).

As IMR is a ventricular disease - that is, it not only a valvular disease - surgical ventricular restoration, if indicated, may be the treatment of choice. However, if such an approach is not feasible, then alternative techniques related to the left ventricular geometry without damaging the left ventricle should be considered. Left ventricular remodeling should also be carefully considered in the future. Based on the above viewpoints, CT may represent a good choice, as it can ameliorate the severe tethering and eliminate the need for left ventricular remodeling. Moreover, surgical ventricular restoration will not be necessary because CT can maintain the valvular-ventricular continuity, with no excessive tension in the papillary muscles; that is, a constant distance is maintained between the papillary muscles and the mid-septal mitral annulus.

Study limitations

The primary limitation of the study was that the samples were highly heterogeneous, and the population and period of follow up were extremely small. The improvements in left ventricular function might also have been affected by other procedures. However, Rodriguez et al. have suggested previously that left ventricular function would be worsened after secondary chordal cutting in an acute ovine IMR model, because of a decrease in the preload recruitable stroke work (7).

In conclusion, the aim of chordal cutting is to decrease anterior leaflet tethering at the cost of left ventricular systolic geometry and/or function. In these pilot studies, CT - when used in conjunction with secondary chordal cutting - might represent a promising technique for preserving valvular-ventricular interaction in FMR patients. However, additional investigations will be required to verify these claims.

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