Cut-and-Transfer Technique for Ischemic Mitral Regurgitation and Severe Tethering of Mitral Leaflets

Giangiuseppe Cappabianca, MD, Samuele Bichi, MD, Davide Patrini, MD, Pasquale Pellegrino, MD, Camillo Poloni, MD, Elena Perlasca, MD, Marianna Redaelli, MD, and Giampiero Esposito, MD

Department of Cardiac Surgery, “Humanitas Gavazzeni” Hospital, Bergamo, Italy

Background. Chronic ischemic mitral regurgitation (MR) denotes abnormal function of normal leaflets resulting from left ventricular enlargement. We present the midterm results of a tailored mitral repair technique using a combination of the following subvalvular procedures: (1) detachment and reimplantation of secondary chordae on the free edge of the anterior leaflet (“cut-and-transfer” technique), (2) relocation of the posterior papillary muscle (PPM) closer to the mitral annulus, and (3) infarct plication on the lateral wall of the left ventricle.

Methods. From 2008 to 2011, 49 patients with moderate to severe ischemic MR underwent coronary surgery plus mitral valve repair using the cut-and-transfer and PPM relocation techniques. All the patients received a “true-sized” semirigid complete annuloplasty ring. In 20 patients, a plication of the lateral wall of the left ventricle was performed to reduce the tethering of the mitral leaflets. The mean number of coronary grafts per patient was 3.4 ± 0.4.

Results. Hospital mortality was 2%. No patient died during 1-year follow-up and New York Heart Association (NYHA) class improved from 3.4 ± 0.5 to 1.4 ± 0.6 (p < 0.0001). The 1-year echocardiogram showed the following changes from baseline: mitral regurgitation grade (0–4) 2.9 ± 0.4 versus 0.2 ± 0.4 (p < 0.0001), left ventricular end-systolic volume index (mL/m²) 52.7 ± 13.1 versus 48.2 ± 10.1 (p = 0.07), left ventricular end-diastolic index (mL/m²) 92.9 ± 16.5 versus 83.4 ± 15.9 (p < 0.005), and ejection fraction (%) 37.8 ± 6.3 versus 44.2 ± 8.1 (p < 0.0001).

Conclusions. Both clinical and echocardiographic results show that reducing the tethering of the mitral leaflets with tailored interventions on subvalvular apparatus without undersizing the mitral annulus can safely and effectively correct chronic ischemic MR.

© 2013 by The Society of Thoracic Surgeons

Accepted for publication June 3, 2013.


Address correspondence to Dr Cappabianca, Department of Cardiac Surgery, Humanitas Gavazzeni, Via Mauro Gavazzeni 21, Bergamo, 24125, Italy; e-mail: giangi_cappabianca@libero.it.
distance between the PPM and the annulus by shortening the anteroposterior diameter of the left ventricle (Fig 3).

Since 2008 we have systematically adopted these 3 techniques in patients with chronic ischemic MR and severe tethering of the mitral leaflets. In this article we describe the 1-year results of this approach.

Patients and Methods

From August 2008 to August 2011, 152 consecutive patients with moderate to severe ischemic MR underwent elective mitral valve repair and coronary artery bypass grafting (CABG) by a single surgeon. Ethics approval for this study was granted by our institutional research ethics board. Patients undergoing urgent or emergency operations, as well as patients undergoing valve operations other than mitral valve repair, were excluded from this study. Preoperatively these patients underwent transthoracic transesophageal echocardiography (TEE) and cardiac magnetic resonance imaging to assess the degree and mechanisms of MR and to evaluate the viability of the left ventricle. Forty-nine of these patients presented with severe tethering of the mitral leaflets, defined as a tenting area 2.5 cm² or greater or a coaptation depth greater than 10 mm, and they constituted the population of this study.

All patients in the study group underwent cut and transfer of the secondary chordae to a primary position of the anterior leaflet and PPM relocation. They all received a complete semirigid true-sized (not undersized) annuloplasty ring, with the only aim being to contain further annular enlargement. The mitral repairs were performed through the roof of the left atrium with a previously described technique [19]. Twenty patients
with a left ventricular end-diastolic diameter greater than 7 cm and a thin-walled dyskinetic area larger than 2-cm wide in the short axis on TEE, which was confirmed to be a transmural scar of the lateral wall by cardiac magnetic resonance imaging, also underwent surgical plication of the left ventricle.

**Echocardiographic Measurement**

Quantitative assessment of the MR was achieved preoperatively using transthoracic echocardiography and was confirmed intraoperatively by TEE in standardized hemodynamic conditions (mean systolic blood pressure ≥ 90 mm Hg, pulmonary artery wedge pressure ≥ 15 mm Hg) by measuring the vena contracta width (VCw) of the regurgitant jet, which was defined as the narrowest portion of the jet that occurs at the orifice or just downstream from it. VCw was measured in the parasternal long-axis view in at least 3 cardiac cycles and was then averaged. VCw larger than 7 mm was considered severe. The tenting area was defined as the area enclosed by the mitral leaflets and the annular plane. The coaptation depth was defined as the shortest distance between the leaflet coaptation and the annular plane.

**Surgical Technique**

After general anesthesia was induced, the heart was accessed through a midsternotomy, and 300 mg/kg of heparin were given intravenously. The ascending aorta and right atrium were cannulated, the latter with a single 2-stage cannula. CO2 was insufflated into the pericardium. Cardiopulmonary bypass was instituted with 2-stage cannula. After general anesthesia was induced, the heart was accessed through a midsternotomy, and 300 mg/kg of heparin were given intravenously. The ascending aorta was completely deflated by applying suction on the root vent, and it was gently displaced by the assistant exposing the left atrial roof. An incision of the left atrial roof was performed parallel to the superior vena cava and the ascending aorta between the lower edge of the right pulmonary artery and the right atrium, carefully avoiding the sinoatrial node artery normally running below the lower end of this incision. The details and results of this approach through the left atrial roof have been recently reported [19]. A Ross retractor was used to expose the mitral valve. A sequential assessment of the mitral scallops and a hydrodynamic test were performed to confirm the mechanism of the MR. All the ring stitches (2-0 polyester) were positioned to further improve the visualization of the mitral valve through the left atrial roof.

The tethering of the anterior leaflet was addressed first: The secondary chordae attached to the central part of the anterior leaflet (usually in the area between A2 and A3) and originating from the PPM, normally 2 or 3 chordae, were cut immediately below their attachment to the leaflet and reimplanted on the free edge of the anterior leaflet with 5-0 Prolene. The relocation of the PPM was then performed: a 4-0 Gore-Tex (W.L. Gore & Associates, Inc, Flagstaff, AZ) double-armed suture was secured to the fibrous portion of the PPM with a double pledget and then both strings were passed through the posterior mitral annulus at the level of the posterior commissure between A3 and P3. All patients received a complete semirigid ring (Memo 3D, Sorin, Saluggia, Italy). In all patients, the ring was sized according to the manufacturer’s guidelines, measuring with the sizer the height of the anterior leaflet and the intercommissural distance. The ring size selected corresponded to the height of the anterior leaflet first and then to the intercommissural distance, and no undersizing was performed.

Eventually, another hydrodynamic test was performed to evaluate the coaptation of the leaflets and to define the correct length of the PPM relocation stitch that was tied at

![Image](image-url)
this stage on the atrial side of the mitral annulus on a pledget.

The left atrium was then closed with a 4-0 Prolene (Ethicon, Somerville, NJ) running suture. Once the air was removed, the cross-clamp was detached and the heart was reperfused. The next steps, including weaning from cardiopulmonary bypass and chest closure, were performed with conventional techniques. Once cardiopulmonary bypass was discontinued, a dynamic quality control of the mitral repair was performed using TEE while maintaining a mean systemic blood pressure of 90 mm Hg or greater and a pulmonary wedge pressure 15 mm Hg or greater, having as a target the absence of any residual regurgitation jet and a coaptation reserve of the mitral leaflets of at least 8 mm.

Follow-Up

The follow-up was complete for all 48 discharged patients. Follow-up length ranged between 12 and 24 months, and the mean was 17.4 ± 3.5 months. All patients had an outpatient appointment and underwent TEE 6 weeks and 1 year after the operation and after that once a year or earlier if clinically indicated.

Statistical Analysis

Categorical variables are presented as absolute numbers and percentages. Continuous variables are presented as mean ± standard deviation. Continuous variables were compared using the t test. The statistical software used was Stat-View 5.0 statistical software package (SAS Institute Inc, Cary, NC).

Results

Preoperative characteristics are summarized in Table 1. The mean number of coronary artery bypasses was 3.4 ± 0.4 per patient. The mean size of the annuloplasty ring was 28.8 ± 3 mm. Mean cardiopulmonary bypass and cross-clamp times were 133 ± 24 minutes and 109 ± 12 minutes, respectively. Only 1 patient died in the same admission as his operation (2.2%) because of acute distress respiratory syndrome. Two patients (4.3%) underwent reexploration for bleeding. Four patients (8.6%) required an intraaortic balloon pump postoperatively. Eleven patients (23.9%) required more than 72 hours in the intensive care unit because of slow weaning from inotropic agents. Five patients (10.8%) required ultrafiltration because of acute renal failure. No patient in this series experienced cerebrovascular accidents or surgical site infections. The mean intensive care unit stay was 3.9 ± 2.1 days and the mean postoperative stay was 10.3 ± 4.7 days.

All discharged patients were alive at 6 weeks and 1 year of follow-up, and NYHA class improved from 3.4 ± 0.5 to 1.4 ± 0.6 (p < 0.0001). NYHA class transitions are reported in Fig 4. No late deaths were reported after the first year. TEE findings are depicted in Table 2: At 1 year the coaptation depth of the mitral leaflet was significantly reduced and no significant MR was found in 39 patients (81.2%), whereas 8 (16.7%) patients were found to have mild-to-moderate MR (VCw < 3 mm), and 1 patient (2.1%) with severe MR underwent reoperation for mitral valve replacement 1.6 years after the first operation.

Comment

Moderate-to-severe chronic ischemic MR is a marker of extensive myocardial dysfunction and, not surprisingly, 10-year survival data after coronary surgical intervention with or without correction of the MR can be as low as 39% [20]. The benefits of mitral annuloplasty for ischemic MR during CABG are still controversial: A classic retrospective propensity-matched comparison of 390 patients undergoing CABG with or without mitral repair for chronic ischemic MR at the Cleveland Clinic showed no survival or symptomatic benefit at 5 and 10 years in patients undergoing mitral repair [20]. One-year failure

Table 1. Preoperative Characteristics

<table>
<thead>
<tr>
<th>Patients (n)</th>
<th>49</th>
</tr>
</thead>
<tbody>
<tr>
<td>Male sex</td>
<td>32 (65.3%)</td>
</tr>
<tr>
<td>Age (y)</td>
<td>61 ± 9</td>
</tr>
<tr>
<td>EuroSCORE</td>
<td>8 ± 2.5</td>
</tr>
<tr>
<td>NYHA class</td>
<td>3.4 ± 0.5</td>
</tr>
<tr>
<td>COPD</td>
<td>7 (15%)</td>
</tr>
<tr>
<td>Previous CVA</td>
<td>4 (8.1%)</td>
</tr>
<tr>
<td>Creatinine &gt; 140 μmol/L</td>
<td>10 (20.4%)</td>
</tr>
<tr>
<td>Ejection fraction (%)</td>
<td>37.8 ± 6.3</td>
</tr>
<tr>
<td>Moderate MR</td>
<td>12 (24.5%)</td>
</tr>
<tr>
<td>Severe MR</td>
<td>37 (75.5%)</td>
</tr>
</tbody>
</table>

COPD = chronic obstructive pulmonary disease; CVA = cerebrovascular accident; MR = mitral regurgitation; NYHA = New York Heart Association.
Table 2. Transthoracic Echocardiographic Findings

<table>
<thead>
<tr>
<th>Transthoracic Echo Findings</th>
<th>Preoperative</th>
<th>1 Year</th>
<th>p Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>MR grade (0–4)</td>
<td>2.9 ± 0.4</td>
<td>0.2 ± 0.4</td>
<td>&lt;0.0001</td>
</tr>
<tr>
<td>LVEDVI (mL/m²)</td>
<td>52.7 ± 13.1</td>
<td>48.2 ± 10.1</td>
<td>0.07</td>
</tr>
<tr>
<td>LVEDVI (mL/m²)</td>
<td>92.9 ± 16.5</td>
<td>83.4 ± 15.9</td>
<td>0.005</td>
</tr>
<tr>
<td>EF (%)</td>
<td>37.8 ± 6.3</td>
<td>44.2 ± 8.1</td>
<td>&lt;0.0001</td>
</tr>
<tr>
<td>CD (mm)</td>
<td>13.1 ± 2.8</td>
<td>6.7 ± 3.5</td>
<td>&lt;0.0001</td>
</tr>
</tbody>
</table>

CD = coaptation depth; EF = ejection fraction; LVEDVI = left ventricular end-diastolic volume index; LVESVI = left ventricular end-systolic volume index; MR = mitral regurgitation.

rates of undersized mitral annuloplasty, the most commonly performed surgical repair of ischemic MR, is 15% to 30% and goes up to 50% in patients with a preoperative mitral tenting area larger than 1.6 cm² [21]. Calafiore and colleagues [22] have advocated mitral valve replacement if the coaptation depth exceeds 10 mm. Such high mitral repair failure rates may explain the reported lack of long-term survival and symptomatic benefits in patients undergoing undersized mitral annuloplasty for chronic ischemic MR. The main reason behind these poor results is likely the progressive nature of the left ventricular dysfunction in these patients. Nevertheless, we believe that a conceptual issue behind the undersized annuloplasty technique is to reconstitute the coaptation of functionally restricted mitral leaflets by downsizing the mitral valve area rather than reducing the tethering of the mitral leaflets. A dobutamine stress echocardiographic assessment described by Magne and coworkers [23] shows that undersized mitral annuloplasty repairs can induce functional mitral stenosis. With these perspectives, we believe that the most innovative concept arising from our study is the possibility of correcting chronic ischemic MR using a true-sized annuloplasty ring and a combination of subvalvular procedures aimed at reducing the functional restriction of the mitral leaflets. Our 1-year data suggest not only that this approach is safe and yields good results in terms of survival and symptom improvement but also that echocardiographic data showed a statistically significant left ventricular reverse remodeling and a failure rate of the mitral repairs of 18.3% (8 patients had mild-to-moderate MR, 1 patient had severe MR and had undergone mitral replacement). This figure, although on a small sample, was achieved in a high-risk group of patients with severe tethering of the mitral leaflets and seems to outperform the 15% to 30% failure rate reported in the literature for an "all-comer" population of patients undergoing undersized annuloplasty repair irrespective of the degree of leaflet tethering [21].

The main caveat of our approach is its technical complexity compared with the annuloplasty ring repair in the context of a combined CABG operation on an already dysfunctional left ventricle. In our series, the mean number of coronary bypasses per patient was 3.4 and the mean cross-clamp time was 103 minutes, taking into account that 40% of the patients also underwent left ventricular plication and that the mitral repairs were performed through the roof of the left atrium. These data suggest that this approach should be reserved for selected patients with severe tethering of the mitral leaflets and should be performed only in the presence of considerable experience in repairing the mitral subvalvular apparatus.

Only a few clinical reports are available on PPM relocation techniques in patients with functional MR: in 2002 Kron and colleagues [13] described 2-month echocardiographic results of this technique in 18 patients with ischemic MR. In 2009 Langer and colleagues [14] reported satisfactory 2-year results of the “ring and string” technique in 30 patients, which was essentially an undersized annuloplasty ring plus a pledged polytetrafluoroethylene chordae anchored to the PPM, exteriorized through the aortomitril continuity, and tied onto a loaded and beating heart under transesophageal echocardiographic monitoring [14]. In 2012 Fattouch and associates [15] described the results in 25 patients of a complex 3-dimensional transesophageal echocardiographic model to calculate the new position of the PPM to achieve a target coaptation depth of 6 mm, and in the same year they also published the results of a 1:1 propensity-matched comparison in 55 patients between those undergoing PPM relocation with true-sized annuloplasty rings according to Kron et al’s [13] technique and those undergoing restrictive annuloplasty only, showing a lower incidence of MR recurrence in the PPM relocation group [24]. Our approach could represent a further evolution of Kron et al’s technique: in fact, the isolated relocation of the PPM moves the papillary muscle vertically (but not medially) toward the posterior commissure and resolves completely the tethering of the posterior leaflet, but frequently the correction of the anterior leaflet tethering is partial. This could cause asymmetrical MR, either from residual tethering of the anterior leaflet or an overcorrection and prolapse of the posterior leaflet while trying to normalize the anterior height. For this reason, in case of severe tethering, the translocation of the secondary chordae of the anterior leaflet becomes essential to equalize the height of both leaflets.

Chordal cutting techniques have been experimentally tested on animals in a number of studies with good results [10, 25, 26], but the evidence in humans is still very limited. In 2007 Borger and associates [11] reported a series of 43 patients with chronic ischemic MR who underwent cutting of the secondary chordae of the anterior and posterior leaflets plus mitral annuloplasty, which he compared with a nonrandomized control group who underwent only mitral annuloplasty. Better 2-year durability was seen in the chordal cutting group, with no evidence of an impairment of left ventricular function from the partial interruption of the mitroventricular continuity. Another report by Fayad and colleagues [27] showed an alternative approach to mitral chordal cutting for chronic ischemic MR through an aortotomy in 5 patients.

Chordal translocation, the technique that we adopted to preserve the mitroventricular continuity, is even less represented in the literature, with only an experimental study and a series of 13 patients, both by Masuyama and
colleagues [28, 29], in patients who underwent secondary chordae transposition for chronic ischemic MR with encouraging results. Therefore, our series is currently the largest reported on this type of mitral repair, presenting the results of a tailored combination of 3 subvalvular techniques aimed at reducing the restriction of both mitral leaflets. Other techniques have also been proposed to address the issue of mitral leaflet tethering: Leaflet extension has been described in sheep [30] and in a report of 2 patients by Dobre and coworkers [31]. The Alfieri stitch has been also tested in 143 patients with chronic ischemic MR in a Cleveland Clinic series, with discouraging results in terms of MR recurrence [32].

The main limitations of this study are its retrospective design, the small sample size, and the lack of a control group of patients with a similar degree of mitral tethering undergoing mitral repair with undersized annuloplasty rings to have more solid data on the durability and effectiveness of this approach.

In conclusion, in this small retrospective series of patients with chronic ischemic MR and severe tethering, a tailored intervention on the subvalvular apparatus seems to have effectively reduced the tethering forces on the mitral leaflets and corrected the MR without under- sizing the mitral annulus. This approach achieved satisfactory results in terms of symptom improvement and mitral repair durability. Nevertheless, a larger sample size, a longer follow-up, and a randomized comparison with patients undergoing undersized mitral annuloplasty are necessary to benchmark the validity of this approach in this specific subgroup of patients.

References
DISCUSSION

DR AUBREY GALLOWAY (New York, NY): This was a very nice and innovative approach to this problem. I did not see a report of the preoperative left ventricular end-diastolic diameter. As we know for the report from Professor Robert Dion and others, most patients with ischemic mitral insufficiency and an end-diastolic diameter less than 6.5 have late excellent results from repair with annuloplasty alone, showing reverse ventricular remodeling and a very low incidence of recurrent late mitral insufficiency. Some data suggest use of preoperative coaptation depth to assess the degree of the tethering and to predict the likelihood of recurrent insufficiency, while others leaflet angle acuity.

Given the good results with annuloplasty alone in most patients, what were your absolute indications to do this more complicated procedure? Do you have data on the preoperative end-diastolic diameter on these patients?

DR ESPOSITO: Thank you for the question. What we consider, as you see here, is the end-diastolic volume, which when is more than 80 mL is really a problem, and we try to approach this issue and to reduce also the ventricle with the left ventricular plication.

The second problem is the seagull effect, because especially the anterior leaflet is addressed from this type of anatomical modification due to posterior papillary muscle displacement. So in this way, when we see in the echo this modification of the mitral complex, especially for the anterior leaflet, we perform this type of technique. These are 2 more important characteristics that we take in account as an indication for this type of operation.

DR VINAY BADHWAR (Pittsburgh, PA): This is obviously an involved procedure to handle a sometimes vexing problem that is present globally. I have 2 follow-up questions. First, prior to you embarking on this procedure, what has been your experience with mitral replacement in this population? Second, are you able to teach this procedure to your other institutional colleagues, residents, or other Italian colleagues?

DR ESPOSITO: This is a very good question. We started, of course, with the replacement of the valve in ischemic mitral regurg, but what we do now is to respect the age of the patient. If the age is more than 70, we have to be sure that the result of the operation is good. Also, replacing the valve is a very difficult operation.

About the learning curve of this type of operation, it is very easy to perform the cutting through the aorta, not from the left atrium, of course. This is the reason why I started to teach my collaborators to do this type of approach through the aorta and not from the atrium, which is really a little bit more difficult. The relocation is very easy and it doesn’t take a lot of time, of course.

DR BADHWAR: How many chords in general? Is it always two chords?

DR ESPOSITO: Two chords, absolutely. Three is very difficult, but two chords is the usual.

DR BADHWAR: Always Prolene to implant the chords?

DR ESPOSITO: We use 4-0 Prolene to put the chords in the free margin.

DR BADHWAR: To clarify your point, never an undersized ring; it’s a true-sized ring?

DR ESPOSITO: Only true sized, really. With this type of technique, we really have to put a very good ring for the best results.

DR BADHWAR: Thank you very much.