Original Article

Restrictive mitral valve annuloplasty for chronic ischaemic mitral regurgitation: outcomes of flexible versus semi-rigid rings

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Background: Restrictive mitral annuloplasty is the mainstay of surgical correction of chronic ischaemic mitral regurgitation (CIMR). Long-term data on the various types of annuloplasty rings is limited. The aim of this study was to investigate the clinical and echocardiographic outcomes of restrictive mitral annuloplasty in patients with CIMR, comparing the use of flexible versus semi-rigid annuloplasty rings.

Methods: A retrospective review was conducted for 133 patients with CIMR who underwent restrictive mitral annuloplasty at our institution between 1999 and 2015. Patient demographics and postoperative outcomes were analyzed.

Results: Mean age was 61.9±9.2 years and 103 patients (77.4%) were male. All patients underwent coronary artery bypass grafting, with a mean of 3.3±0.8 grafts. Flexible rings was implanted in 39 patients (29.3%, group F) and semi-rigid rings in 94 (70.7%, group R). Preoperative New York Heart Association class was III/IV in 104 patients (78.2%). Mean preoperative left ventricular ejection fraction was 28.8%±10.2%. Preoperative mitral regurgitation was moderate in 51 patients (38.3%) and severe in 82 (61.7%). In-hospital mortality occurred in 11 patients (8.3%). Overall survival at 1, 5 and 10 years were, respectively, 86.4%, 69.7% and 45.9%. At 10 years, overall survival (group F 53.1%, group R 40.0%, P=0.330) and freedom from moderate to severe MR (group F 53.1%, group R 53.8%, P=0.725) did not differ significantly. Freedom from hospitalization for heart failure was 59.3%. Left ventricular reverse remodelling, defined as a reduction of left ventricular end-systolic volume index >15%, occurred more commonly in Group R (51.1%) compared to Group F (23.1%), P=0.003.

Conclusions: Restrictive mitral annuloplasty was associated with an operative mortality of 8.3%. Heart failure symptoms and significant MR recur in approximately 40% of patients after 10 years. Survival remained suboptimal and was not influenced by the type of annuloplasty ring.

Keywords: Ischaemic mitral regurgitation; restrictive mitral annuloplasty; coronary artery disease

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Introduction

In patients with coronary artery disease, chronic ischaemic mitral regurgitation (CIMR), has a negative prognostic effect on survival (1,2). The primary mechanism of CIMR is ischaemia-induced left ventricular remodeling, causing papillary muscle displacement and apical tenting of the mitral valve (MV) leaflets. The mainstay of surgical correction is performing a restrictive mitral annuloplasty (RMA) with an undersized annuloplasty ring. This aims to eliminate mitral regurgitation (MR) by increasing the

coaptive leaflet margins (3).

There are various annuloplasty rings available, including flexible, semi-rigid, partial, and complete rings. The effect of each ring type on the long-term results of mitral annuloplasty remains uncertain. We compared the results of concomitant RMA using a flexible or a semi-rigid ring in patients with CIMR who underwent CABG. Endpoints included overall survival, recurrence of MR, readmissions for heart failure and New York Heart Association (NYHA) class.

Methods

This study is a retrospective review of all patients who underwent CABG with concomitant RMA, between January 1999 and December 2015 at our institution. The study was approved by the local institutional review board with a waiver of patient consent (reference: 2013/680/C). The indication for RMA was the presence of MR of moderate or greater degree. Only patients with CIMR whose primary mechanism of MR was leaflet tethering combined with annular dilatation were included in this study. All patients in this study had a history of at least one previous myocardial infarction or a segmental wall motion abnormality seen on echocardiography. Patients who underwent mitral valve replacement, concomitant aortic valve replacement or surgical ventricular restoration were excluded.

Definitions

Early or operative mortality was defined as mortality within 30 days and/or death before discharge from the index hospitalization. Renal failure was defined as serum creatinine clearance (CrCl) levels lower than 60 mL/min as calculated with the Cockroft–Gault formula, or the need for renal replacement therapy. Respiratory failure was defined as the need for mechanical ventilation for more than 24 h or the need for reintubation. Left ventricular reverse remodeling (LVRR) was defined as a reduction in left ventricular end-systolic volume index (LVESVI) >15% (4). Pulmonary hypertension was defined as pulmonary arterial systolic pressure greater than 50 mmHg.

Surgical technique

All operations were performed via median sternotomy using moderately hypothermic (30–32 ℃) cardiopulmonary bypass instituted with ascending aortic and bicaval cannulation. Aortic cross-clamping, a combination of intermittent blood cardioplegia for myocardial protection and flooding of the surgical field with carbon dioxide was applied in all cases. Intraoperative transesophageal echocardiography was performed routinely in all patients after the induction of anaesthesia to evaluate valvular and ventricular function during surgery. Coronary bypass grafting was performed to all major territories provided that the coronary arteries were not too small (<1.5 mm) or too heavily calcified. Rings were downsized in standard fashion by choosing a ring at least 2 sizes smaller than the measured height of the anterior leaflet. The model of annuloplasty ring was at the surgeon's discretion. The same group of surgeons performed the surgeries during the whole study period. All surgeons used flexible annuloplasty rings [Cosgrove-Edwards (Edwards Lifesciences, Irvine, CA), Duran (Medtronic, Minneapolis, MN), and St Jude Tailor (St. Jude Medical, St. Paul, Minnesota)] until Oct 2007, after which a transition of institutional practice towards the use of semi-rigid annuloplasty rings [Physio, Physio II (Edwards Lifesciences, Irvine, CA), St Jude Saddle (St. Jude Medical, St. Paul, Minnesota) and CG Future (Medtronic, Minneapolis, MN)] was adopted. All surgeons used semi-rigid rings after Oct 2007.

Surgical techniques remained largely unchanged during the study period. No patients required reinstitution of cardiopulmonary bypass for correction of greater than mild residual MR.

Echocardiography

All patients underwent a preoperative transthoracic echocardiography. The severity of MR was assessed by experienced cardiologists, integrating quantitative and supporting echocardiographic parameters, according to existing recommendations (5,6). Left ventricular function was evaluated by measuring the ejection fraction and the end-systolic volume (LVESV) according to the modified biplane Simpson's method. Pulmonary artery systolic pressure was extrapolated from Doppler study of the tricuspid flow.

Data and follow-up

Patient data was collected from case-notes and electronic medical records during each hospitalization. Collected data included baseline demographics, perioperative clinical variables and echocardiographic data. Data regarding follow-up was obtained by direct assessment during scheduled clinic reviews at our institution.

Table 1 Preoperative clinical data

Variable	All patients (n=133)	Group F (n=39)	Group R (n=94)	P value
Demographics				
Age (years)	61.9±9.2	62.4±10.2	61.7±8.7	0.796
Gender (male), n (%)	103 (77.4)	29 (74.4)	74 (78.7)	0.584
BSA (m^2)	1.66±0.14	1.66±0.15	1.66±0.14	0.708
Comorbidities, n (%)				
Diabetes mellitus	66 (49.6)	15 (38.5)	51 (54.3)	0.097
Renal failure (CrCl <60 mL/min)	23 (17.3)	7 (17.9)	16 (17.0)	0.898
Hypertension	83 (62.4)	21 (53.8)	62 (66.0)	0.189
Hyperlipidaemia	84 (63.2)	24 (61.5)	60 (63.8)	0.803
Peripheral vascular disease	19 (14.3)	6 (15.4)	13 (13.8)	0.816
Previous stroke	18 (13.5)	3 (7.7)	15 (16.0)	0.205
Atrial fibrillation	12 (9.0)	4 (10.3)	8 (8.5)	0.749
COPD	5 (3.8)	1 (2.6)	4 (4.3)	0.641
NYHA class III or IV	104 (78.2)	31 (79.5)	73 (77.7)	0.816

Values for continuous variables are expressed as mean ± standard deviation. BSA, body surface area; COPD, chronic obstructive pulmonary disease; CrCl, creatinine clearance; LVEF, left ventricular ejection fraction; NYHA, New York Heart Association.

Statistical analysis

Statistical analyses were performed with the Statistical Package for Social Science, version 17 (SPSS, Chicago, IL, USA). Continuous variables were expressed as means with standard deviation. These were compared using a two-tailed *t*-test. Categorical variables, expressed as percentages, were analyzed with χ^2 or Fisher's exact test. Preoperative and postoperative echocardiographic parameters were compared using a paired sample t-test. Survival function and freedom from morbid events were presented using Kaplan-Meier survival curves and comparisons performed with log-rank test. Cox multivariable regression analysis was used to identify the independent predictors of long-term outcomes. Preoperative and operative variables with a univariate P<0.10 or those judged to be clinically important were entered into the multivariate Cox model. All two-tailed P values <0.05 were taken as significant.

Results

Between 1999 and 2015, 133 consecutive patients with CIMR underwent CABG with concomitant RMA at our institution. Thirty-nine patients (29.3%) received a flexible annuloplasty ring (Group F) and 94 (70.7%) had a semi-rigid ring implanted (Group R). A variety of rings were used within each group. In Group F, 33 patients (84.6%) received a Cosgrove-Edwards ring, 3 (7.7%) received a Duran ring, and 3 (7.7%) had a St. Jude Medical Tailor ring implanted. In Group R, 64 (68.1%) received a Physio or Physio II ring, 27 (28.7%) received a CG Future ring, and 3 (3.2%) had a St. Jude Medical Saddle implanted. Sixteen patients (12.0%) underwent concomitant tricuspid valve annuloplasty with a rigid MC3 ring (Edwards Lifesciences, Irvine, CA).

Preoperative clinical data are shown in *Table 1*. There were no significant differences in baseline characteristics between both groups. At presentation, 29 patients (21.8%) were in NYHA class II, 59 (44.4%) in class III, and 45 (33.8%) in class IV. Preoperative echocardiographic data were similar between the two groups (*Table 2*). Surgical data are presented in *Table 3*. All patients underwent CABG, with a mean of 3.3±0.8 grafts. Compared to Group F, a larger proportion of patients in Group R underwent concomitant tricuspid annuloplasty. Intraoperative transoesophageal echocardiogram showed mild (1+) or less MR after MV repair in all patients.

Postoperative complications are shown in *Table 4*. Complication rates were similar between Group F and

Table 2 Preoperative echocardiographic data

Variable	All patients (n=133)	Group F (n=39)	Group R (n=94)	P value
MR grade	2.99±0.88	3.15±0.87	2.92±0.88	0.176
Severe, n (%)	82 (61.7)	28 (71.8)	54 (57.4)	0.121
Moderate, n (%)	51 (38.3)	11 (28.2)	40 (42.6)	0.121
LVEF (%)	28.8±10.2	31.3±10.9	27.8±9.5	0.067
LAESD (mm)	46.4±6.3	46.0±6.4	46.5±6.3	0.718
LVESD (mm)	49.4±9.0	47.8±10.4	49.9±8.5	0.295
LVESVI (mL/m^2)	73.9±32.7	70.7±32.4	75.0±32.9	0.537
LVEDD (mm)	60.8±7.4	59.7±8.0	61.2±7.2	0.357
PASP	51.4±15.8	52.7±13.8	51.1±16.3	0.690
PASP >50 mmHg, n (%)	70 (52.6)	25 (64.1)	45 (47.9)	0.290

Values for continuous variables are expressed as mean ± standard deviation. LAESD, left atrial end-systolic diameter; LVEDD, left ventricular end-diastolic diameter; LVEF, left ventricular ejection fraction; LVESD, left ventricular end-systolic diameter; LVESVI, left ventricular end-systolic volume index; MR, mitral regurgitation; PASP, pulmonary artery systolic pressure.

Table 3 Operative data

Variable	All patients (n=133)	Group F (n=39)	Group R (n=94)	P value
Emergency surgery	8 (6.0)	2 (5.1)	6 (6.4)	0.782
CPB time (min)	156±28	155±26	156±29	0.839
AXC time (min)	96±22	91±21	97±22	0.136
Number of bypass grafts	3.3±0.8	3.2±0.7	3.3±0.8	0.702
Annuloplasty ring size (mm)	27.0±1.5	27.0±1.4	27.0±1.5	0.975
Intraoperative IABP	54 (40.6)	17 (43.6)	37 (39.4)	0.651
Tricuspid valve annuloplasty	16 (12.0)	1 (2.6)	15 (16.0)	0.031

Values for continuous variables are expressed as mean ± standard deviation. AXC, aortic cross clamp; CPB, cardiopulmonary bypass; IABP, intra-aortic balloon pump.

Group R, except for acute renal failure which was more common in Group R (P=0.016). In-hospital mortality occurred in 11 patients (8.3%), 4 (10.3%) in the flexible ring group and 7 (7.4%) in the semi-rigid ring group (P=0.592). Seven patients (5.3%) died from multi-organ failure and 4 (3.0%) died from sepsis. All surviving patients were discharged from hospital with mild or less MR. Clinical follow-up and late echocardiographic data were 100% complete for the 122 patients who survived to hospital discharge. The mean follow-up period was 6.7±4.0 years (Group F: 8.7±4.1 years *vs.* Group R: 5.7±3.6 years, P<0.001). The mean echocardiographic follow-up period was 6.0±3.6 years (Group F: 7.6±3.8 years *vs.* Group R: 5.1±3.3 years, P=0.007).

Late survival

Fifty-six patients (42.1%) died during the follow-up period, including in-hospital deaths. Within this group, 26 patients (46.4%) died of acute myocardial infarction or congestive cardiac failure. The Kaplan-Meier survival curve for all patients is shown in *Figure 1*. The degree of preoperative MR [moderate *vs.* severe (*Figure 2*)] did not affect long-term survival (P=0.937). Comparing Groups F and R (*Figure 3*), overall survival at 5 years was (Group F, 71.3%±7.3%; Group R, 69.0%±5.5%) and at 10 years (Group F,

Table 4 Postoperative complications

Variable	All patients (n=133)	Group F (n=39)	Group R (n=94)	P value
Low cardiac output syndrome	7 (5.3)	3 (7.7)	4 (4.3)	0.419
Acute renal failure	32 (24.1)	4 (10.3)	28 (29.8)	0.016
Respiratory failure	12 (9.0)	3 (7.7)	9 (9.6)	0.730
Re-exploration for bleeding	5 (3.8)	1 (2.6)	4 (4.3)	0.641
Sternal wound infection	5 (3.8)	2 (5.1)	3 (3.2)	0.593
Stroke	3 (2.3)	0 (0)	3 (3.2)	0.259

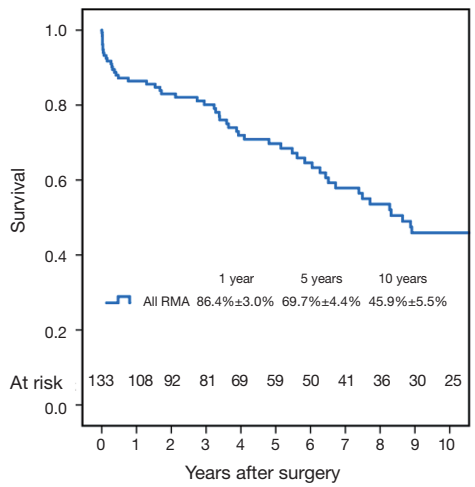

Figure 1 Survival after CABG and RMA. CABG, coronary artery bypass grafting; RMA, restrictive mitral annuloplasty.

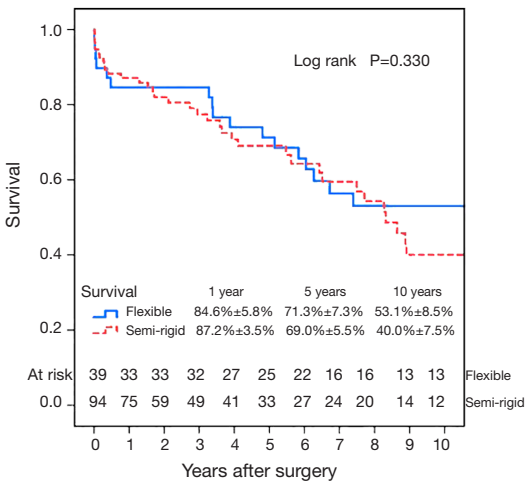

Figure 3 Survival after CABG and RMA, stratified for the type of mitral ring. CABG, coronary artery bypass grafting; RMA, restrictive mitral annuloplasty.

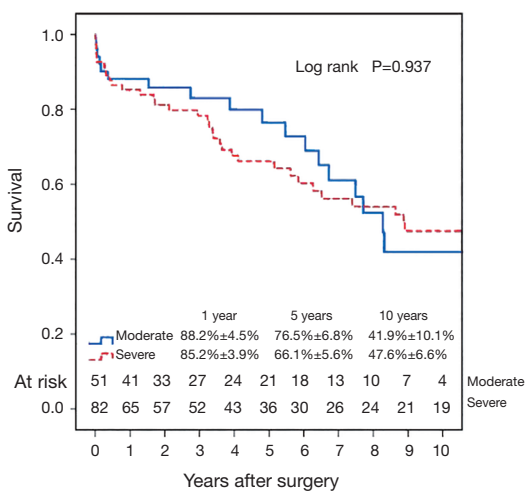

Figure 2 Survival after CABG and RMA, stratified for the degree of preoperative MR. CABG, coronary artery bypass grafting; RMA, restrictive mitral annuloplasty; MR, mitral regurgitation.

53.1%±8.5%; Group R, 40.0%±7.5%). There were no statistical differences in the survival rates between Group F and Group R (P=0.330).

Multivariable Cox regression analyses showed that older age [P=0.001; hazard ratio (HR) =1.08 per year; 95% confidence interval (CI), 1.03–1.13] and the presence of preoperative atrial fibrillation (P=0.004; HR =4.05; 95% CI, 1.56–10.50) were associated with decreased long-term survival. Variables analyzed included the severity of preoperative MR (moderate/severe), age, type of annuloplasty ring (semi-rigid/flexible), gender, preoperative LVEF, preoperative atrial fibrillation and preoperative LV end-systolic diameter.

Late echocardiographic follow-up

Echocardiography was performed every 1 to 2 years

Table 5 Latest echocardiographic data

Variable	All patients (n=133)	Group F (n=39)	Group R (n=94)	P value
MR Grade	1.10±0.85*	1.40±0.93*	0.97±0.78*	0.008
LAESD (mm)	44.3±7.3*	46.0±6.5	43.4±7.6*	0.071
LVESD (mm)	46.5±10.9*	47.6±10.8	45.9±10.9*	0.369
LVESVI (mL/m^2)	63.2±32.6*	68.3±29.7	61.3±33.5*	0.284
LVEDD (mm)	56.5±8.6*	58.1±7.6	55.8±9.3*	0.203
MPG (mmHg)	4.0±1.8	3.5±1.9	4.1±1.7	0.118
LVEF (%)	32.6±13.2*	33.8±14.5	32.1±12.7*	0.524
PASP	44.0±17.3*	51.4±18.8	41.0±15.8*	0.012
PASP >50 mmHg	40 (30.1)	18 (46.2)	22 (23.4)	0.042
LVRR (%)	57 (42.9)	9 (23.1)	48 (51.1)	0.003

Values for continuous variables are expressed as mean ± standard deviation. *, P<0.05 versus preoperative data. LAESD, left atrial end-systolic diameter; LVEDD, left ventricular end-diastolic diameter; LVEF, left ventricular ejection fraction; LVESD, left ventricular end-systolic diameter; LVESVI, left ventricular end-systolic volume index; LVRR, left ventricular reverse remodeling; MPG, mean pressure gradient; MR, mitral regurgitation; PASP, pulmonary artery systolic pressure.

for patients with mild or less MR and 6-monthly for patients with recurrent moderate or greater MR. The latest postoperative echocardiographic data are shown in *Table 5*. Overall, the severity of MR was significantly reduced from 2.99±0.88 at baseline to 1.10±0.85 at latest follow-up. This improvement was evident in both groups. Compared to baseline, the left ventricular dimensions, left atrial dimensions, left ventricular ejection fraction and pulmonary artery systolic pressures improved significantly only in patients from Group R. Compared to Group F, postoperative pulmonary artery systolic pressures were significantly lower in Group R (P=0.012).

Left ventricular reverse remodeling occurred in 51.1% of patients in the semi-rigid ring group compared to 23.1% in the flexible ring group (P=0.003). Thirty-two patients (24.1%) had moderate or worse recurrent MR during follow-up. *Figure 4* shows the Kaplan–Meier estimate for recurrent moderate to severe MR in all patients. The severity of preoperative MR was not a predictor of recurrent moderate to severe MR (*Figure 5*). Comparing Groups F and R (*Figure 6*) at 5 years, freedom from recurrent moderate to severe MR was (Group F, 73.6%±7.6%; Group R, 65.2%±8.1%), and at 10 years (Group F, 53.1%±11.5%; Group R, 53.8%±9.9%). There were no statistical differences in the recurrence rates of MR between Group F and Group R (P=0.725).

Multivariable Cox regression analysis showed that an increased left ventricular end-systolic diameter (LVESD) was associated with an increased recurrence of moderate or worse (≥2+) MR (P=0.017; HR =1.08 per mm increase in LVESD; 95% CI, 1.01–1.14). The type of annuloplasty ring and degree of preoperative MR did not influence the recurrence of MR. Variables analyzed included the severity of preoperative MR (moderate/severe), age, type of annuloplasty ring (semi-rigid/flexible), gender, preoperative LVEF, preoperative atrial fibrillation and preoperative LV end-systolic diameter. There were no complications of ring dehiscence in either group.

Hospitalization for heart failure and NYHA class

Figure 7 shows the Kaplan–Meier estimate for freedom from hospitalization for heart failure. Compared to patients with preoperative moderate MR (*Figure 8*), hospitalization for heart failure occurred more frequently in patients with preoperative severe MR (P=0.023). Comparing Groups F and R (*Figure 9*), freedom from hospitalization for heart failure at 5 years was (Group F, 76.2%±7.4%; Group R, 71.8%±6.3%) and at 10 years (Group F, 67.2%±8.9%; Group R, 50.8%±10.7%). There were no statistical differences in the rates of hospitalization for heart failure between Group F and Group R (P=0.345). Amongst the 77 survivors at the latest follow-up, 40 (51.9%) were in NYHA class I, 22 (28.6%) in class II, 13 (16.9%) in class III and 2 (2.6%) in class IV.

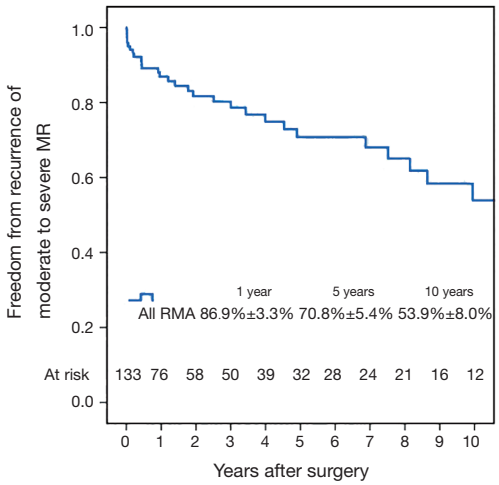

Figure 4 Freedom from recurrence of moderate to severe MR after CABG and RMA. CABG, coronary artery bypass grafting; RMA, restrictive mitral annuloplasty; MR, mitral regurgitation.

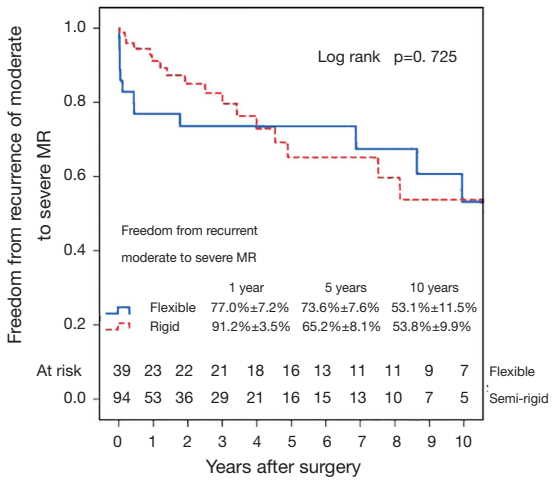

Figure 6 Freedom from recurrence of moderate to severe MR after CABG and RMA, stratified for the type of mitral ring. CABG, coronary artery bypass grafting; RMA, restrictive mitral annuloplasty; MR, mitral regurgitation.

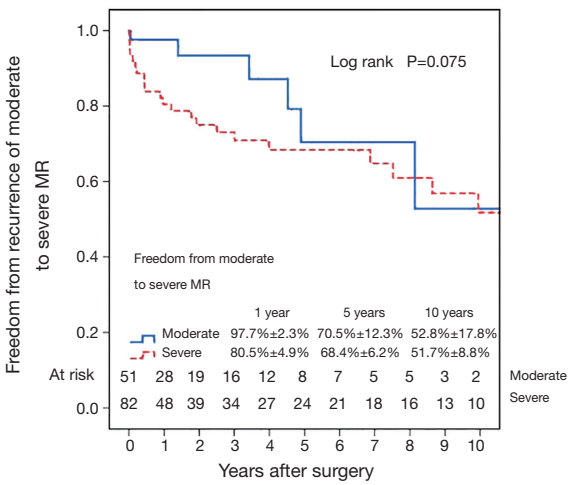

Figure 5 Freedom from recurrence of moderate to severe MR after CABG and RMA, stratified for the degree of preoperative MR. CABG, coronary artery bypass grafting; RMA, restrictive mitral annuloplasty; MR, mitral regurgitation.

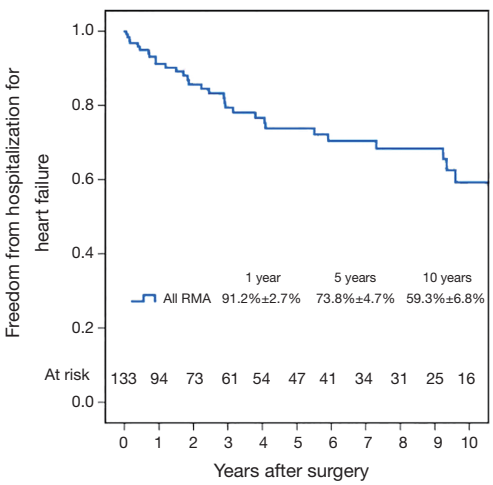

Figure 7 Freedom from hospitalization for heart failure after CABG and RMA. CABG, coronary artery bypass grafting; RMA, restrictive mitral annuloplasty.

Reoperation

No patients underwent reoperative open heart surgery. One patient (0.8%) underwent a percutaneous valve-in-valve procedure for recurrent severe MR, 9.1 years after the initial surgery.

Discussion

This study provides information on early and late clinical outcomes of patients undergoing RMA for CIMR, in a cohort of patients with severely depressed LVEF. More than half (52.6%) of these patients had pulmonary hypertension. In contrast to patients with primary MR, the benefit of MV surgery for CIMR remains uncertain. In a small randomized study of 31 patients with moderate CIMR, RMA using a rigid ring was initially effective at reducing the degree of MR but no difference was found in terms of residual MR, LV dimensions and function, or clinical outcomes at

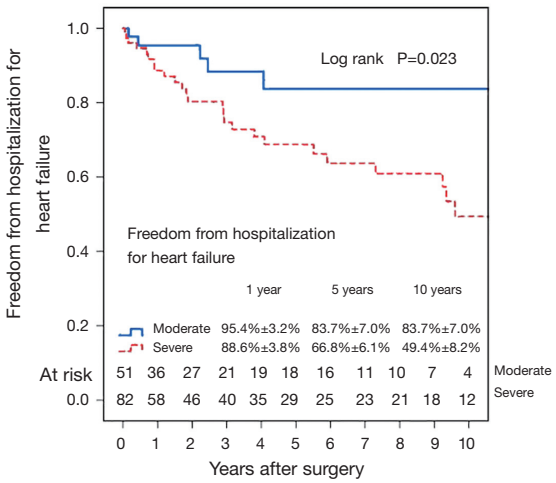

Figure 8 Freedom from hospitalization for heart failure after CABG and RMA, for the degree of preoperative MR. CABG, coronary artery bypass grafting; RMA, restrictive mitral annuloplasty.

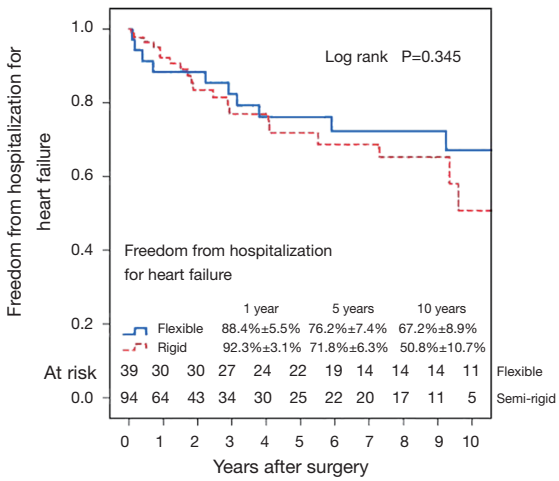

Figure 9 Freedom from hospitalization for heart failure after CABG and RMA, stratified for the type of mitral ring. CABG, coronary artery bypass grafting; RMA, restrictive mitral annuloplasty.

1 year when compared to patients who underwent CABG alone (7). Despite its efficacy in reducing MR, a survival advantage of adding MV annuloplasty to CABG has not been demonstrated (8-10).

Our current study cohort consists of patients with severely impaired LVEF undergoing high-risk CABG with RMA. The in-hospital mortality in our cohort (8.3%) is comparable with results published previously, ranging from 3.5% to 10.3% (11-17).

Long-term survival

In a cohort of 290 patients with moderate (52%) or severe MR (48%) who underwent CABG with RMA at the Cleveland Clinic, 1-, 5-, and 10-year survival were respectively, 92%, 74%, and 39% (9). Wong *et al.* reported 1, 5, and 10-year survival rates of 84%, 68%, and 37% respectively, in a group of 251 patients with moderate ischaemic MR who underwent CABG and RMA (8). In the present study, long-term survival was decreased in patients undergoing CABG & RMA at an older age and in patients with pre-existing atrial fibrillation. The degree of preoperative MR (moderate or severe) did not affect long-term survival.

In line with results from previous studies, there was no effect of annuloplasty type on survival in our cohort (11,18,19). In contrast, Silberman *et al.* reported a survival advantage associated with semi-rigid annuloplasty rings, compared to flexible rings (16).

Recurrence of MR

At 5 years, 29% of our patients developed recurrent moderate or severe MR, increasing to 46% at 10 years. These rates are comparable to previously published data, ranging from 11.2% to 32.6% (9,10,18,20,21). Contrary to other studies which report that significant recurrent MR tends to occur within the first 6 months, the recurrence of MR in our series occurred at a consistent rate throughout the follow-up period (9,18). The use of a non-flexible ring appears to significantly reduce the need for reoperation for recurrent MR (22).

Factors predisposing to recurrence of MR

Previously described preoperative factors associated with a higher rate of recurrence of MR after annuloplasty include increased preoperative left ventricle dilation with LVEDD >65 mm (15), higher severity of preoperative MR (18,19), lower preoperative left ventricular ejection fraction (18,19), anterior leaflet tethering (4), and presence of a basal aneurysm or dyskinesis (23). Recurrent MR is also more frequent with use of partial bands or flexible complete rings, although recurrence rates remain high even with complete rigid rings (10,11,18,20,22).

In the present study, the preoperative LVESD was the

only predictor of recurrent moderate to severe MR. The type of annuloplasty ring and degree of preoperative MR did not influence the recurrence of MR. Re-intervention rates for recurrent moderate or greater MR were very low, as patients either declined or were assessed to be unfit for high-risk reoperative surgery.

Reverse remodelling

Despite aggressive downsizing during RMA, no patients experienced functional mitral stenosis. In the present study, a reduction in the degree of MR was observed with both ring types. However, the effect was more pronounced in patients who received semi-rigid rings. Left ventricular reverse remodeling occurred more frequently in patients who received a semi-rigid annuloplasty ring. This may be explained by semi-rigid rings potentially being able to dictate annular shape, stabilize the annular diameter and maintain a fixed inter-trigonal and septal-lateral distance. Despite LVRR occurring more frequently in patients receiving a semi-rigid ring, long-term survival and recurrence of moderate or severe MR did not differ significantly from patients receiving a flexible ring. Braun and associates (24) found that preoperative LVEDD of 65 mm or less or LVESD of 51 mm or less were predictive for LVRR, and this conferred a survival advantage (15).

NYHA class

At 5 years, 26% of our cohort required readmission for heart failure, with this figure rising to 41% at 10 years. In a previous report by Mihaljevic and associates, 23% of patients who underwent CABG + mitral annuloplasty were in NYHA functional class III/IV at 5 years (9). In our series, patients with preoperative severe MR were more likely to be readmitted for heart failure. The Cardiothoracic Surgical Trials Network (CTSN) has provided valuable randomized data from their respective studies on moderate and severe CIMR (25,26). In patients with moderate CIMR, the 2-year rate of moderate or severe residual MR was higher in the CABG-alone group than in the CABG + RMA group (32.3% *vs.* 11.2%, P<0.001). Restrictive mitral annuloplasty provided a more durable correction of MR but did not significantly improve survival or reduce overall adverse events or readmissions (25). In patients undergoing MV repair (RMA) or replacement for severe CIMR, there were no significant differences in LVRR or survival at 2 years. Mitral regurgitation recurred more frequently in the repair group (58.8% *vs.* 3.8%, P<0.001), resulting in more heart-failure-related adverse events and cardiovascular admissions (26). A meta-analysis of 22 studies (3,815 patients with CIMR) demonstrated significantly reduced perioperative mortality and late mortality following MV repair, compared to MV replacement. Recurrence of at least moderate MR was higher following MV repair (RR, 5.21; 95% CI, 2.66–10.22; P<0.001) (27).

Alternative approaches

In attempts to improve the durability of RMA, 3-dimensional rings have been developed. Using a porcine model, Bouma *et al.* proposed that the use of undersized saddle-shaped annuloplasty rings (Medtronic Profile 3D (Medtronic, Minneapolis, MN)] in MV repair for CIMR improves leaflet coaptation, which may improve repair durability (28).

Campisi *et al.* reported impressive results from a study of 157 patients undergoing RMA with the ETlogix ring (Edwards Lifesciences, Irvine, Calif). This annuloplasty ring has a 3-dimensional design for targeted correction of the asymmetric deformation of P2–P3 segments in CIMR. At a median echocardiographic follow-up of 28 months, freedom from ≥2+ MR was 96.6% (14).

Mitral annuloplasty in CIMR does not prevent coronary artery disease from progressing. By reducing the septolateral dimension of the mitral annulus and increasing leaflet coaptation, RMA only tackles one aspect of the problem related to CIMR. To improve this, subvalvular techniques specifically targeting malpositioned papillary muscles have been described. These techniques have shown promising results (29-31).

Limitations

This is a retrospective observational study with inherent biases in data collection. Due to the small sample size, statistical analyses may have been underpowered. Being conducted at a single centre, the surgical technique and postoperative care adopted were standardized. The same group of surgeons performed the surgeries throughout the study period. However, our results may not be generalizable to all centres. Viability studies were not conducted routinely and hence unavailable for analysis. Also, advanced echocardiographic measurements such as coaptation height, tenting area and tethering height were not recorded

routinely in the earlier years of this study and were not analyzed. There was also a temporal difference in the usage of the two classes of rings.

Conclusions

In this study of 133 patients with CIMR, CABG and RMA with either a flexible or semi-rigid ring, reduced MR and relieved symptoms. Operative mortality was 8.3%. Despite LVRR occurring more frequently in patients receiving a semi-rigid ring, survival and recurrence of significant MR were not influenced by the type of ring used. Survival and durability of MV repair in patients with CIMR remain suboptimal, with heart failure symptoms and significant MR recurring in approximately 40% of patients after 10 years. Adjunct subvalvular techniques may play a role in improving outcomes.

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Footnote

Conflicts of Interest: The authors have no conflicts of interest to declare.

Ethical Statement: The authors are accountable for all aspects of the work in ensuring that questions related to the accuracy or integrity of any part of the work are appropriately investigated and resolved. The study was approved by the local institutional review board with a waiver of patient consent (reference: 2013/680/C).

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