CARDIOVASCULAR MEDICINE

Functional and prognostic implications of left ventricular contractile reserve in patients with asymptomatic severe mitral regurgitation

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Objective: To evaluate contractile reserve (CR) determined by exercise echocardiography in predicting clinical outcome and left ventricular (LV) function in asymptomatic severe mitral regurgitation (MR).

Design: Cohort study.

Setting: Regional cardiac centre.

Patients and outcome measures: LV volumes and ejection fraction (EF) were measured at rest and after stress in 71 patients with isolated MR. During follow up (mean (SD) 3 (1) years), EF and functional capacity were serially assessed and cardiac events (cardiac death, heart failure, and new atrial fibrillation) were documented.

Results: CR was present in 45 patients (CR+) and absent in 26 patients (CR–). Age, resting LV dimensions, EF, and MR severity were similar in both groups. Mitral surgery was performed in 19 of 45 (42%) CR+ patients and 22 of 26 (85%) CR– patients. In patients undergoing surgery, CR was an independent predictor of follow up EF ($p = 0.006$) and postoperative LV dysfunction ($EF < 50\%$) persisted in five patients, all in the CR– group. Event-free survival was lower in surgically treated patients without CR ($p = 0.03$). In medically treated patients, follow up EF was preserved in those with intact CR but progressively deteriorated in patients without CR, in whom functional capacity also deteriorated.

Conclusions: Evaluation of CR by exercise echocardiography may be useful for risk stratification and may help to optimise the timing of surgery in asymptomatic severe MR.

Asymptomatic patients with chronic severe mitral regurgitation (MR) may develop irreversible left ventricular (LV) dysfunction despite a “normal” resting ejection fraction (EF). Early mitral valve repair surgery on the basis of severe MR alone is supported by evidence of the effectiveness of valve repair^{1,2} and the poor long term outcome incurred by deferring surgery until symptoms develop.^{3,4} However, some patients are not good surgical candidates, because of advanced age or co-morbidities, and some valves are not repairable. Moreover, valve repair carries a small operative mortality⁵ and the durability of valve repair for degenerative mitral valve disease is not guaranteed, with a reported recurrence rate of MR (grade ≥ 1) of 8.3% a year after repair.⁶ Therefore, while some asymptomatic patients may indeed be candidates for early surgery, a more conventional strategy of watchful waiting remains a reasonable option for others. The major challenge is therefore to detect LV contractile dysfunction at an early stage so that surgical correction can be instituted to prevent the development of irreversible LV dysfunction.

On the basis of previous work that suggested the usefulness of exercise echocardiography in unmasking latent LV contractile dysfunction preoperatively,⁷ we perform exercise echocardiography in patients with asymptomatic severe MR where an immediate decision to proceed to surgery is not indicated because of concerns about the valve or the patient. We sought to assess whether evaluation of contractile reserve (CR) by exercise echocardiography could predict long term LV function and clinical outcome in a cohort of medically and surgically treated patients with asymptomatic severe MR.

METHODS

Study patients

We prospectively followed up 71 patients (23 women, mean (SD) age 60 (14) years) with moderately severe to severe isolated MR, in New York Heart Association (NYHA) functional class I ($n = 59$) or II (12 (17%)) who underwent exercise echocardiography to assess CR. To minimise additional factors that may affect LV function, we excluded patients with significant coronary artery disease, previous cardiac surgery (including coronary bypass surgery), coexisting aortic valve disease, and mitral stenosis. The majority of patients (59 (83%)) were in sinus rhythm, with 12 in rate controlled atrial fibrillation. Apart from two patients with rheumatic heart disease (3%) and one with infective endocarditis (1%), the aetiology of MR was exclusively degenerative, with involvement of the posterior leaflet in 46 patients (65%), anterior leaflet prolapse in three (4%), and bileaflet prolapse in 19 (27%).

Baseline rest and stress echocardiography

All patients underwent symptom limited exercise testing with either a treadmill (Bruce protocol, $n = 58$) or an upright exercise bicycle (two minute stages with 25 W increments, $n = 13$). Symptoms and ECG were monitored continuously during exercise and blood pressure was measured non-invasively at rest and every three minutes during and after exercise. Haemodynamic responses to exercise and estimated exercise capacity (metabolic

Abbreviations: CR, contractile reserve; EF, ejection fraction; LV, left ventricular; METS, metabolic equivalents; MR, mitral regurgitation; NYHA, New York Heart Association

Table 1 Comparison of baseline clinical characteristics and surgery details between patients with (CR+) and without contractile reserve (CR–)

	CR+ (n = 45)	CR– (n = 26)	p Value
Age (years)	58 (16)	65 (11)	0.08
Men	31 (69%)	17 (65%)	0.77
Weight (kg)	74 (16)	72 (15)	0.72
MR severity grade 4+	22 (49%)	15 (58%)	0.48
NYHA class II	8 (18%)	4 (15%)	0.80
Atrial fibrillation	5 (11%)	7 (27%)	0.09
Medications			
ACE inhibitor	20 (45%)	17 (67%)	0.13
β Blocker	5 (10%)	3 (10%)	0.96
Digoxin	5 (10%)	4 (14%)	0.65
Diuretic	1 (3%)	1 (5%)	0.80
Surgery	19 (42%)	22 (85%)	0.001
Time to surgery (months)	12 (10)	11 (15)	0.84
Mitral valve repair	15 (79%)	15 (68%)	0.45
Aortic cross clamp time (min)	55 (12)	58 (22)	0.68
Pump time (min)	81 (11)	87 (22)	0.50
Follow up interval (months)	33 (19)	35 (14)	0.73

Values are mean (SD) or number (%).

ACE, angiotensin converting enzyme; MR, mitral regurgitation; NYHA, New York Heart Association.

equivalents (METs)) were recorded and conventional end points for exercise testing were applied. All but eight patients achieved $\geq 85\%$ of their age predicted maximum heart rate with exercise.

All patients underwent transthoracic echocardiography in the left lateral decubitus position at rest and immediately after exercise. Echocardiograms were recorded with commercially available equipment (Acuson Sequoia, Siemens, Erlangen, Germany) with digital capture into a quad screen, cine loop format, saved on optical disks and videotape. At rest, the LV end systolic and end diastolic dimensions and the thickness of the interventricular septum and posterior wall were measured according to the recommendations of the American Society of Echocardiography.⁸ The mechanism of MR was carefully evaluated and its severity was assessed both on colour Doppler and (when possible) by regurgitant orifice jet criteria⁹ as either moderately severe (3+, n = 34) or severe (4+, n = 37). In the apical four chamber view, the endocardial border was traced, excluding the papillary muscles, to obtain LV end diastolic and end systolic volumes by the modified Simpson's rule. EF was calculated from the difference between the end diastolic and end systolic volumes at rest and immediately after exercise. The difference

between the resting and post-exercise EF was defined as the CR. On the basis of previous data,⁷ 45 patients with a post-exercise EF increment of $\geq 4\%$ were defined as CR+ and those without, as CR– (n = 26).

Follow up

All patients were followed up for 3 (1) years. The treating cardiologist made the decision to operate on both CR+ and CR– patients on the basis of all available information, including the results of our study. Generally, surgery followed the development of symptoms (progression of NYHA functional class) or change in echocardiographic variables (increasing LV end systolic dimensions and falling EF). Serial resting echocardiograms (as described in the baseline study) were repeated and recorded at six, 12, and 24–36 months. Thirty four patients repeated the exercise testing to re-evaluate functional capacity (expressed as METs) and CR. All patients were closely followed up for the occurrence of cardiac events (defined as the combined end point of cardiac death, heart failure, and new atrial fibrillation). Follow up information was obtained by clinic or telephone review.

Table 2 Baseline rest and exercise echocardiographic measurements in CR+ and CR– patients

Variable	CR+ (n = 45)	CR– (n = 26)	p Value
Rest			
LVEDD (cm)	5.8 (0.7)	5.8 (0.8)	0.97
LVESD (cm)	3.3 (0.4)	3.4 (0.6)	0.48
LVEDVrest (ml)	118 (35)	122 (43)	0.70
LVESVrest (ml)	43 (16)	44 (19)	0.85
EFrest (%)	64 (7)	64 (7)	0.86
Exercise			
LVEDVexe (ml)	103 (37)	95 (27)	0.38
LVESVexe (ml)	27 (14)	42 (13)	<0.0001
EFexe (%)	74 (8)	56 (8)	<0.0001
Δ EF (%)	10 (6)	–8 (9)	<0.0001
Peak RPP ($\times 1000$)	28 (6)	27 (6)	0.45
Functional capacity			
METs	7.8 (3.6)	5.1 (1.5)	0.001
VO ₂ max (ml/kg/min)	24.8 (9.9)	15.8 (6.0)	0.004

Values are mean (SD).

Δ EF, ejection fraction increment with exercise; EFexe, ejection fraction with exercise; EFrest, ejection fraction at rest; LVEDD, end diastolic diameter; LVEDVexe, end diastolic volume with exercise; LVEDVrest, end diastolic volume at rest; LVESD, end systolic diameter; LVESVexe, end systolic volume with exercise; LVESVrest, end systolic volume at rest; METs, metabolic equivalents; RPP, rate–pressure product; VO₂max, maximum oxygen consumption.

Table 3 Univariate and multivariate predictors of follow up left ventricular ejection fraction (LVEF) for CR+ and CR− patients in the combined group (both medically and surgically treated patients)

Univariate			Multivariate		
Variable	r	p Value	Coefficient	CI	p Value
Intercept	NA	NA	70	64 to 76	<0.0001
CR	0.47	<0.0001	−9.7	−13.9 to −5.4	<0.0001
EFexe	0.35	0.003	NA	NA	NA
Surgery	−0.32	0.007	NA	NA	NA
LVESVrest	−0.31	0.01	0.21	−0.33 to −0.08	0.002
LVESVexe	−0.31	0.01	NA	NA	NA
LVEDVrest	−0.29	0.02	NA	NA	NA

Follow up LVEF was $70 - (0.21 \times \text{LVESVrest}) - 9.7$ for CR− or $70 - (0.21 \times \text{LVESVrest})$ for CR+ patients (model $r^2 = 0.30$, $p < 0.0001$). Age, male sex, functional capacity (metabolic equivalents (METs) or $\text{VO}_{2\text{max}}$), peak RPP, peak heart rate, peak systolic blood pressure, atrial fibrillation, pulmonary hypertension, weight, ACE inhibitor use, LVEDD, LVESD, EFrest, and LVEDVexe were not significantly correlated with follow up LVEF on bivariate analysis.
CI, confidence interval; NA, not applicable.

Statistical analysis

Group data were expressed as mean (SD) or percentages. Groups were compared by the paired or unpaired Student's *t* test for continuous variables or χ^2 test for categorical variables. Simple linear regression analysis was used to estimate correlations between continuous variables. A stepwise multiple linear regression model was used to identify baseline predictors of follow up LVEF. The effect of CR incremental to end systolic volume was examined by sequential models. The rates of survival free from cardiac events were displayed by the Kaplan Meier method. Follow up time was defined from time of baseline exercise echocardiography. Cardiac event-free survival of CR+ and CR− patients was directly compared by the log rank test. The statistical package SPSS for Windows (release 11.0; SPSS Inc, Chicago, Illinois, USA) was used for statistical analysis. Significance was defined as a two tailed $p < 0.05$.

RESULTS

Clinical characteristics

Table 1 summarises the clinical characteristics and surgical details of CR+ and CR− patients. Clinical characteristics did not differ significantly between the groups. Among medically treated patients, two were in atrial fibrillation and six were taking angiotensin converting enzyme inhibitors or angiotensin receptor blockers.

Baseline exercise echocardiography

Table 2 shows the baseline resting and post-exercise LV dimensions and volumes and exercise indices of CR+ and CR− patients. Resting echocardiographic variables did not

differ significantly between the groups. As expected from the definition of CR, the exercise LV end systolic volume was significantly lower and the exercise EF and EF increment with exercise were significantly higher in the CR+ patients (all $p < 0.0001$). Functional capacity as measured by maximum oxygen consumption and estimated METs was significantly higher in the CR+ patients ($p = 0.004$ and $p = 0.001$, respectively).

Mitral valve surgery

Mitral valve surgery was performed in 19 of 45 patients (42%) in the CR+ group (mean delay 12 (9) months after exercise echocardiography) and 22 of 26 (85%) CR− patients (mean delay 11 (14) months after exercise echocardiography). The majority of patients in both groups underwent valve repair, and the proportion who underwent repair did not differ significantly between the groups (79% *v* 68%, $p = 0.45$). With the exception of one CR− patient, all other patients who underwent valve repair had concomitant insertion of an annuloplasty ring. All patients who underwent valve replacement had preservation of the chordae. The cross clamp time and bypass time did not differ significantly between CR+ and CR− groups ($p = 0.68$ and $p = 0.5$), between patients who developed postoperative LV dysfunction and those who had preserved postoperative LV function ($p = 0.51$ and $p = 0.39$), or between patients who developed cardiac events and those who did not ($p = 0.15$ and $p = 0.99$). The remaining 26 CR+ patients continued medical treatment; baseline clinical or echocardiographic variables did not differ significantly between CR+ patients who remained well with medical treatment and those who subsequently required surgery. Of the four medically treated

Table 4 Univariate and multivariate predictors of follow up LVEF for CR+ and CR− patients in the surgical group

Univariate			Multivariate		
Variable	r	p Value	Coefficient	CI	p Value
Intercept	NA	NA	72	63 to 81	<0.0001
LVESVrest	−0.42	0.007	−0.29	−0.47 to −0.11	0.002
CR	0.41	0.008	−8.5	−14.3 to −2.6	0.006
LVEDVrest	−0.37	0.02	NA	NA	NA
LVESVexe	−0.35	0.03	NA	NA	NA
EFexe	0.34	0.03	NA	NA	NA

Follow up LVEF was $72 - (0.29 \times \text{LVESVrest}) - 8.5$ for CR− or $72 - (0.29 \times \text{LVESVrest})$ for CR+ patients (model $r^2 = 0.33$, $p < 0.0001$). Age, male sex, functional capacity (METs or $\text{VO}_{2\text{max}}$), peak RPP, peak heart rate, peak systolic blood pressure, atrial fibrillation, pulmonary hypertension, weight, ACE inhibitor use, LVEDD, LVESD, EFrest, and LVEDVexe were not significantly correlated with follow up LVEF on bivariate analysis.

Figure 1 Follow up ejection fraction (EF) in surgically treated patients with (CR+) and without contractile reserve (CR-). EF expressed as mean (SD). * $p = 0.16$; † $p = 0.02$; ‡ $p = 0.008$.

CR- patients, three were not operated on due to significant co-morbidities and one refused surgery.

Predictors of follow up LVEF

Table 3 and table 4 summarise the univariate and multivariate predictors of follow up EF for the combined group and the surgical group. In the combined group, linear regression analysis showed both CR ($p < 0.0001$) and rest LV end systolic volume ($p = 0.002$) to be independent predictors of follow up EF (model $R = 0.55$). This effect was not only independent of end systolic volume but also incremental, as shown by the lower predictive power of the model in the absence of CR (model $R = 0.42$). In the medical group, CR was the only variable correlated with follow up EF ($r = 0.35$, $p = 0.06$). In the surgical group, both CR ($p = 0.006$) and rest LV end systolic volume ($p = 0.002$) were independent predictors of follow up EF.

Figure 1 shows the follow up LVEF for surgically treated CR+ and CR- patients. Early postoperative EF decreased significantly in both CR+ (66 (8)% to 54 (6)%, $p = 0.006$) and CR- patients (64 (6)% to 47 (8)%, $p < 0.0001$) at six months, although the decrement was greater in the CR- patients. However, postoperative EF subsequently improved at 12 months in both groups. At 36 months, the follow up EF was significantly lower than preoperative EF for both CR+ (59 (8)% v 66 (8)%, $p = 0.008$) and CR- patients (50 (11)% v 64 (6)%, $p < 0.0001$). After surgery EF was higher in the CR+ group than in the CR- group at six, 12, and 24–36 months ($p = 0.02$, $p = 0.16$, and $p = 0.008$, respectively). Post-surgery EF at 36 months did not differ significantly between patients who underwent mitral valve repair and those who had mitral valve replacement (54 (10)% v 56 (13)%, $p = 0.6$).

All CR+ patients had preserved late postoperative LV function at 12 months, but five of 22 (23%) CR- patients had persistent postoperative LV dysfunction, defined as EF $< 50\%$ based on previous data.⁵ The rest preoperative echocardiographic variables did not differ significantly between CR- patients who developed postoperative LV dysfunction and those with a preserved postoperative LV function.

Figure 2 shows the follow up LVEF in medically treated CR+ and CR- patients. EF was maintained in the CR+ patients but progressively deteriorated in the CR- patients (61 (6)% to 54 (14)%, $p = 0.20$). Compared with the CR+

Figure 2 Follow up EF in medically treated CR+ and CR- patients. EF expressed as mean (SD). * $p = 0.37$; † $p = 0.06$.

group, follow up EF was lower in the CR- group at 12 months (55 (17)% v 61 (9)%, $p = 0.37$) and 24–36 months (54 (14)% v 62 (6)%, $p = 0.06$).

In the surgical group, the follow up LV end diastolic volumes decreased in both the CR+ (130 (33) ml to 101 (42) ml, $p = 0.007$) and CR- patients (120 (40) ml to 100 (40) ml, $p = 0.08$) with a greater decrease in the CR+ group. The follow up LV end diastolic volumes did not change significantly in the medically treated CR+ (109 (36) ml to 110 (31) ml, $p = 0.98$) or CR- patients (82 (19) ml to 117 (28) ml, $p = 0.49$). The follow up LV end systolic volumes also did not change significantly in either the medically treated CR+ (41 (16) ml to 41 (13) ml, $p = 0.90$) or CR- patients (32 (2) ml to 45 (20) ml, $p = 0.53$) or surgically treated CR+ (42 (16) ml to 40 (22) ml, $p = 0.77$) or CR- patients (40 (15) ml to 49 (34) ml, $p = 0.29$).

Follow up functional capacity

Among surgically treated patients, preoperative and post-operative functional capacity did not differ significantly in either CR+ (7.1 (1.8) v 7.2 (2.2) METS, $p = 0.93$) or CR- patients (5.0 (1.2) v 5.3 (1.4) METS, $p = 0.54$).

Figure 3 summarises the functional capacity in medically treated CR+ patients. Those with CR+ had a preserved exercise capacity (9.1 (4.0) METS v 8.1 (4.1) METS, $p = 0.06$) but this deteriorated in the medically treated CR- patients. Functional capacity of the medically treated CR- group was not further analysed due to the small number of patients.

Figure 3 Comparison of baseline and follow up functional capacity in medically treated CR+ patients.

Figure 4 Event-free survival in surgically treated CR+ and CR- patients.

Clinical outcome

Eight events occurred in the study cohort resulting in an overall event rate of 11%. No perioperative or late cardiac deaths occurred in the surgically treated patients. An ischaemic stroke occurred in one CR- patient (one week after surgery) and prosthetic valve endocarditis developed in another patient (five months after surgery). Five late postoperative cardiac events occurred during the follow up period, all in the CR- group, of whom three patients had mitral valve repair and two had mitral valve replacement. Three patients developed clinical evidence of heart failure (at 16, 20, and 30 months after surgery); all had persistent postoperative LV dysfunction and one required hospitalisation. None of the patients who developed heart failure had significant postoperative recurrence of MR (grade ≥ 1). Two patients developed new onset atrial fibrillation (at six and 14 months after surgery). No cardiac events occurred in the surgically treated CR+ patients. Survival free from cardiac events was significantly lower in the CR- group than in the CR+ group (log rank 4.73, $p = 0.03$) (fig 4). Only 50% of the CR- patients were free of cardiac events at 38 months after surgery.

Among the medically treated patients, one patient in the CR+ group died of non-cardiac causes. No cardiac deaths or events occurred in either group. No further analysis was attempted in this group because of the small number of events.

Interobserver and intraobserver variability

The intraobserver variability in the measurement of rest LV end diastolic and end systolic volumes was 4.9 (10.4) ml ($r = 0.97$) and -0.9 (3.5) ml ($r = 0.99$), respectively, corresponding to a variability in rest EF of -2 (4)%. After exercise, the variability was -0.8 (9.5) ml for end diastolic volume ($r = 0.98$), -0.9 (3.2) ml for end systolic volume ($r = 0.99$), and -1 (2)% for EF. Values for interobserver variability were similar.

DISCUSSION

This study shows that in asymptomatic patients with chronic severe MR and normal resting LV function, an impaired CR detected on exercise echocardiography predicts the development of late LV dysfunction and postoperative cardiac

morbidity in surgically treated patients and progressive deterioration of LV function in medically treated patients. Conversely, an intact CR is a reassuring finding that predicts preservation of LV function and a favourable clinical outcome in both medically and surgically treated patients.

Prediction of follow up LVEF in MR

Previous studies have shown the usefulness of end systolic diameter,^{5 10} end systolic wall stress,¹¹ EF,^{5 10} and Doppler derived dp/dt ¹² in predicting postoperative LVEF. Although abnormal preoperative LVEF is a powerful predictor of postoperative LV dysfunction^{1 3} and subsequent cardiac morbidity and mortality,^{5 13} resting EF in severe MR may remain normal despite the presence of significant LV contractile dysfunction. Thus, while a reduced preoperative EF identifies patients with a poor postoperative outcome, a normal resting EF does not distinguish patients with normal contractility from those with latent LV contractile dysfunction who may benefit from early surgery.

Leung *et al*⁷ showed that exercise echocardiographic variables were more sensitive and specific than rest echocardiographic variables in predicting early postoperative LV dysfunction. In the present study, CR (defined as EF increment with exercise of $\geq 4\%$) was an independent predictor of follow up EF in a multiple linear regression model, a finding valid for both medically and surgically treated patients.

In this study, early postoperative EF decreased significantly in both CR+ and CR- patients, consistent with previous studies,^{2 10} with a greater decrease in the CR- patients. This early decrease does not necessarily indicate ongoing impairment of LV contractile function. However, the greater decrease in the EF in the CR- group probably reflects the presence of superimposed LV contractile dysfunction unmasked by a change in the loading conditions postoperatively. After the initial decrease, late postoperative EF subsequently improved in both CR+ and CR- patients. This implies that preoperative latent LV dysfunction may be reversible postoperatively in some patients due to more normal loading, reverse remodelling, and recovery of LV contractile function. This short term fall in the EF followed by a longer term recovery to normal is consistent with previous studies.^{14 15} However, a subset of our CR- patients had persistent late postoperative LV dysfunction (EF $< 50\%$) implying that some patients with subclinical LV dysfunction before surgery actually have irreversible LV contractile dysfunction. The reduction in follow up LV end diastolic volumes in the surgical group probably reflects correction of LV volume overload postoperatively.

Our findings also suggest that CR may predict follow up EF in medically treated patients. While the value of various preoperative echocardiographic variables in predicting postoperative LV function is well established, there is a relative paucity of data on its value in medically treated patients. In this study, loss of CR is associated with progressive deterioration in follow up EF, findings consistent with previous reports that inability to increase the EF or reduce the end systolic volume with stress are early markers for progressive deterioration in myocardial contractility.^{16 17}

Effect of CR on functional capacity

Although functional capacity was significantly lower in the CR- patients in our study, the degree of functional impairment was not a reliable indicator of the presence or severity of LV dysfunction, reflecting the influence of a variety of non-cardiac factors on functional capacity. Baseline and postoperative functional capacity did not differ significantly in surgically treated patients, irrespective of CR.

The deterioration of functional capacity in medically treated patients without CR is concordant with the deterioration of their LV function. The improvement in the follow up functional capacity of medically treated CR+ patients was surprising. Potential causes are the benefits of medical management including better ventricular rate control in the few patients with atrial fibrillation, better blood pressure control, and lifestyle advice—although these causes were not studied systematically and their role is speculative.

Effect of CR on clinical outcome

An intact CR predicts preservation of LV function and a good clinical outcome in both medically and surgically treated patients. In addition to predicting LV dysfunction in both medically and surgically treated patients, a negative CR was associated with late postoperative cardiac morbidity regardless of whether the valve was repaired or replaced, despite the relatively low risk profile of our study patients. Age, NYHA functional class, and coronary artery disease have been shown in previous studies to be independent predictors of postoperative cardiac morbidity and mortality in patients undergoing surgery for MR.^{3,18} The relatively low cardiac event rate in our study was probably due to the exclusion of patients with coronary artery disease, earlier timing of surgery, and improvement in surgical technique. The absence of cardiac events in the medically treated CR− group is most likely due to the small number of patients and relatively short follow up period.

Study limitations

In this study, LV volumes were measured from the apical four chamber view because the two chamber views taken immediately after exercise were often foreshortened and the anterior wall was often not well seen because of hyperventilation. However, as patients with myocardial infarction were excluded and LV enlargement in MR is usually symmetrical, the use of a single apical four chamber view would be unlikely to cause inaccuracies in volume measurement due to chamber asymmetry.

Some subgroups in the current study were small and the follow up duration was relatively short. Despite the relatively low risk profile of our study patients, we observed a significant difference between CR+ and CR− patients with regard to not just follow up LV function but also late postoperative cardiac morbidity.

With the exception of the CR+ patients who had loss of CR on retesting before surgery, it is difficult to ascertain the actual duration of loss of CR. Future studies that serially evaluate CR before surgery would be useful to define further the optimal time frame for surgery to prevent development of irreversible contractile dysfunction and postoperative cardiac morbidity.

Clinical implications

Despite the trend towards early surgery for asymptomatic MR, not all valves are repairable, and co-morbidity and risks of long term anticoagulation are increasing concerns in the aging population. Evaluation of CR should not be added to decision making in situations where there is an existing

indication for surgery. However, where the risk to benefit ratio of surgery is uncertain, an intact CR is a reassuring finding that predicts the preservation of LV function and functional capacity and a good clinical outcome on medical treatment. Conversely, once CR has been lost, surgery should be performed as soon as possible to prevent the development of irreversible postoperative LV dysfunction and adverse cardiac events. In patients without CR, more intense post-operative follow up is also necessary for the early detection of cardiac events.

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