Long-term outcomes of mitral valve repair with the Classic and Physio rings

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SOUHRN

Kontext: Při plastice mitrální chlopně se dnes ve velké míře používá anuloplastický kroužek (prstenec) Carpentier-Edwards Physio ring, který je zdokonalením klasického tuhého kroužku. Pokusili jsme se srovnat dlouhodobé výsledky anuloplastiky za použití klasického tuhého kroužku (Classic ring, CR) a polotuhého Physio kroužku (PR) při degenerativních změnách na mitrální chlopni.
Metody: V počítačové databázi naší instituce bylo vyhledáno 306 pacientů, u nichž byla v období 2005 až 2015 provedena mitrální anuloplastika s použitím klasického kroužku (CR – 139 pacientů) nebo kroužku Physio (PR – 167 pacientů). Patnáct z nich současně podstoupilo i plastiku trikuspidální chlopně. Z výše uvedeného počtu byla u 92 pacientů (30,1 %) stanovena diagnóza Barlowovy choroby a u 214 pacientů (69,9 %) fibroelastická deficience. Pacienti měli podobné demografické a echokardiografické charakteristiky.
Výsledky: V perioperačním období došlo k úmrtí 4 (1,3 %) pacientů. Průměrná délka sledování byla 107,4 ± 13,2 měsíců. V obou skupinách – ne však mezi nimi – došlo ke statisticky významnému zvětšení průměru levé komory na konci diastoly i systoly. Desetileté přežití dosáhlo 84,6 % (93,1 % v případě CR a 91,5 % u PR; p = 0,255) a po deseti letech došlo k recidivě mitrální regurgitace (MR) ≥ 2+ u 74,5 % pacientů (88,2 % u CR a 86,3% u PR; p = 0,110). Reoperaci pro neúspěšnost plastiky bylo nutno provést v osmi případech s CR a v šesti případech s PR. Podle Coxovy regresní analýzy byly prediktory neúspěšné plastiky Barlowova choroba, preoperační MR = 4+ a zkrácení šlašinek. Univariační analýza prokázala jako prediktory nepříznivé hodnoty přežití vyšší věk (≥ 70 let), funkční třídu NYHA IV a systolický tlak v plicnici (≥ 40 mm Hg).
Závěry: Dlouhodobé výsledky plastiky pro degenerativní MVD s použitím klasického kroužku nebo kroužku Physio jsou srovnatelné. Při degeneraci šlašinek a jejich zkrácení je nutno implantovat umělé šlašinky. Obstrukci výtokového traktu levé komory u Barlowovy choroby lze zcela zabránit použitím velkých kroužků.

Keywords:
Degenerative mitral valve disease
Mitral regurgitation
Mitral valve repair
Rigid ring
Semi-rigid ring

ABSTRACT

Background: The Carpentier-Edwards semi-rigid Physio ring (PR) is considered an improvement of the rigid Classic ring (CR). Hence, the former is nowadays widely used in mitral valve (MV) repair. We sought to compare the long-term outcomes of MV repair with the CR and PR in degenerative mitral valve disease (MVD).
Methods: In a computerized registry of our institution, 306 patients were found to have had MV repair with the CR (139 patients) or PR (167 patients) between 2005 and 2015. Fifteen of them had concomitant tricuspid valve repair. Out of the total number, 92 patients (30.1%) were diagnosed with Barlow's disease and 214 patients (69.9%) with fibroelastic deficiency. Patients in the two ring groups had similar demographic and echocardiographic characteristics.
Results: There were 4 (1.3%) operative mortalities. Mean follow-up time was 107.4 ± 13.2 months. Left ventricular end-diastolic and end-systolic diameters significantly improved in both groups, but were comparable between groups. Survival at ten years was 84.6% (93.1% in CR and 91.5% in PR; p = 0.177) and freedom from recurrent MR > 2+ was 74.5% (88.2% in CR and 86.3% in PR; p = 0.110) at 10 years. Reoperations for repair failure were eight in CR and six in PR. By Cox regression analysis, Barlow's disease, preoperative MR = 4+ and chordal shortening were predictors of repair failure. Old age (≥70 years), NYHA functional class IV and pulmonary artery systolic pressure (≥40 mmHg) were predictors of poor survival by univariate analysis.
Conclusions: Long-term outcomes of repair for degenerative MVD with the Classic and Physio rings are comparable. Artificial chordal implantation should be used instead of chordal shortening for degenerative chordae. Left ventricular outflow tract obstruction in Barlow's disease can be completely avoided by the use of large rings.

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Introduction

Degenerative mitral valve disease (MVD) is an acquired valve pathology that takes many years to manifest. It is the cause of 60–70% of cases of mitral valve (MV) insufficiency in developed nations.[1] Based on clinical patterns and gross appearance, degenerative MVD is classified as either fibroelastic deficiency (FED) or Barlow's disease.[2,3] In FED, the mitral annulus (MA) diameter is normal, a single leaflet segment is involved and the chordae are elongated with/without rupture in the affected segment, whereas Barlow's disease is a severer form characterized by a dilated MA, excessive leaflet growth, multiple segmental involvement, elongated, thickened and ruptured chordae.[4]

Repair of MV failure consists of a valvuloplasty and annuloplasty (with a rigid, semi-rigid or a flexible ring). Annuloplasty rings reduce the MA size and prevent its further dilation thereby restoring proper leaflet coaptation.[5] The range of available rings is quite extensive and reflects the lack of consensus on the features of a durable and effective device. Moreover, there exist no clear principles that guide the choice of one type of ring over another in the clinical practice of most surgeons and so, ring selection is usually based on a surgeon's preference rather than evidence.[6] For degenerative MVD, a balance needs to be struck between rigidity of design which aids in remodelling and flexibility which preserves the dynamic function of the MA.[7] In addition, the incidences of ring-associated systolic anterior motion (SAM), raised trans-mitral pressure gradient and left ventricular (LV) dysfunction must all be considered when choosing an annuloplasty device.[8]

Criticisms of the Carpentier-Edwards rigid Classic ring (CR) of causing SAM with left ventricular outflow tract obstruction (LVOTO) and impairment of LV function led to the development of the semi-rigid Physio ring (PR).[7,9] Whilst there are so many studies that compared other types of rings, to the best our knowledge, only one ran-

Table 1 – Demographic data and mitral valve characteristics

Characteristics	Total	CR	PR
No. of patients (%)	306	139 (45.4%)	167 (54.6%)
Age, (mean y, SD)	71.2 ± 9.2	72.8 ± 9.5	69.6 ± 8.8
Sex			
Male	233	109 (78.4%)	124 (74.3%)
Female	73	30 (21.6%)	43 (25.7%)
Atrial fibrillation	21 (6.9%)	9 (6.5%)	12 (7.2%)
MR grade			
2	6 (2.0%)	1 (0.7%)	5 (3%)
3	147 (48.0%)	82 (59%)	65 (38.5%)
4	153 (50%)	56 (40.3%)	97 (57.4%)
NYHA Functional Class			
I	7 (2.3%)	4 (2.9%)	3 (1.8%)
II	130 (42.5%)	40 (28.8%)	90 (53.9%)
III	150 (49.0%)	84 (60.4%)	66 (39.5%)
IV	19 (6.2%)	11 (7.9%)	8 (4.8%)
Diabetes mellitus	16 (5.2%)	7 (5.0%)	9 (5.4%)
PA systolic pressure ≥40 mm Hg	22 (7.2%)	8 (5.8%)	14 (8.3%)
Degenerative MVD (n, %)			
Barlow	92 (30.1%)	38 (27.3%)	54 (32.3%)
FED	214 (69.9%)	101 (72.7%)	113 (67.7%)
Leaflet involvement (n, %)			
Anterior	29 (9.5%)	7 (9.7%)	22 (13.1%)
Posterior	177 (57.8%)	104 (74.8%)	73 (43.7%)
Bi-leaflet	100 (32.7%)	28 (20.1%)	72 (43.1%)
Leaflet condition (n, %)			
Prolapse	275 (89.9%)	125 (89.9%)	150 (89.8%)
Calcifications	12 (3.9%)	5 (3.6%)	7 (4.2%)
Normal	19 (6.2%)	9 (6.5%)	10 (6.0%)
Chordae (n, %)			
Rupture	184 (60.1%)	84 (60.4%)	100 (59.9%)
Elongations	70 (22.9%)	35 (25.2%)	35 (21.0%)
Normal	52 (17.0%)	20 (14.4%)	32 (19.2%)
Annulus (n, %)			
Dilated, not calcified	290 (94.8%)	129 (92.8%)	161 (96.4%)
Dilated, calcified	11 (3.6%)	7 (5.0%)	4 (2.4%)
Not dilated	5 (1.6%)	3 (2.2%)	2 (1.2%)

CR – classic rigid ring; FED – fibroelastic deficiency; MR – mitral regurgitation; MVD – mitral valve disease; NYHA – New York Heart Association; PA – pulmonary artery; PR – physio semi-rigid ring.

domized study compared the CR and PR in the repair of multi-etiological MVD.[10] This study aimed to compare the long-term outcomes of MV repair for degenerative MVD with these two rings.

Methods

Study design

This is a retrospective, nonrandomized review of all patients who underwent valve reconstruction with either the CR or PR as the primary intervention for degenerative MVD at our institution. The study was approved by the internal Institutional Review Board with a waiver for patient consent.

Patients

A computerized registry of all patients having cardiac surgery at the Vishnevskiy 3rd Central Clinical Hospital was used to identify patients who underwent repair for degenerative MVD (with/without TVR) between 2005 and 2015. Three hundred and six consecutive patients were found to have had valvuloplasty with either CR (139 patients) or PR (167 patients) annuloplasty. Degenerative MVD was identified as either FED or Barlow's disease intraoperatively using the Carpentier and Fornes guidelines.[3,11] Preoperative clinical data collected included patient's age, sex, NYHA functional class, ejection fraction and degree of mitral regurgitation (MR) by preoperative echocardiogram, presence of preoperative atrial fibrillation, diabetes mellitus, and the form of degenerative MVD (Table 1).

Surgical techniques

Patients received MV repair (with concomitant TVR in 15 cases) performed by four surgeons. Intraoperative echocardiography was performed in all patients before and after repair. Exposure was by median sternotomy for most patients, except for 36 patients (11.8%) in whom either minimally invasive thoracotomy or hemi-sternotomy was performed. Moderate hypothermic (28 ± 3 °C) cardiopulmonary bypass was instituted using bicaval and ascending aortic cannulation. Myocardial protection was by antegrade and/or retrograde cold blood cardioplegia. After aortic cross-clamping, MV exposure was through an extended trans-septal incision or through a left atrial incision along Sondergaard's groove.

Prolapse of the posterior leaflet was preferentially corrected by quadrangular resection when the prolapsing segment was billowing with/without chordal rupture or elongation, to remove this diseased part of the valve as much as possible. When the remaining part of the posterior leaflet showed excess tissue (as in Barlow disease), the resection was combined with a sliding leaflet procedure including two triangular resections of the remnants of the non-prolapsing posterior leaflet. If there was no excess tissue in the remaining portion of the posterior leaflet (as in FED), a sliding procedure was performed, but without removal of tissue of the remaining posterior leaflet. Prolapse of the anterior leaflet was corrected by chordal transfer or artificial chordal implantation. Prolapse induced by chordal elongation was treated by chordal shortening. This was done by either chordal burying or papillary muscle repositioning. The latter procedure was mostly used for anterior leaflet prolapse or commissural prolapse of both leaflets.

Table 2 – Operative data

Characteristics	Total	CR	PR	*p*-value
Minimally invasive	36	15	21	0.122
CPB (mean min ± SD)	80.0 ± 27.1	84.9 ± 21.0	97.5 ± 31.0	0.063
Cross-clamp (mean min ± SD)	54.3 ± 18.0	61.1 ± 19.8	57.5 ± 12.9	0.072
Concomitant procedures				
TVR	15	9	6	–
Radiofrequency ablation	21	9	12	–
Valvuloplasty				
Segmental resection leaflet	290	133	157	–
Other leaflet interventions (patch, plicature)	16	6	10	–
Chordoplasty				
Chordal shortening	70	35	35	–
Chordal transfer	13	7	6	–
Chordal replacement with PTFE sutures	57	27	30	–
Without chordoplasty	52	20	32	–
Decalcification of the MA and leaflets	11	7	4	–
Mitral annulus reduction				
By sliding leaflet technique	215	93	122	–
By annulus plication	10	0	10	–
Ring size				
Smaller than 34	189	92	97	–
34 or larger	117	45	72	–

CPB – cardio-pulmonary bypass; CR – classic rigid ring; PR – physio semi-rigid ring; PTFE – polytetrafluoroethylene; TVR – tricuspid valve repair.

A Classic ring or a Physio ring was then inserted for ring annuloplasty after measuring the inter-trigone distance and height of the anterior leaflet. The choice of ring was left to the discretion of the surgeon. After repair, the saline test and then a trans-esophageal echocardiography were performed to determine valve competence. Patients with regurgitant jet area >2 cm^2 or more than trivial MR had a re-repair on the second pump-run. A concomitant radio-frequency ablation was performed for all patients with permanent or paroxysmal atrial fibrillation present for at least 6 months before surgery. In every patient, the specific surgical repair techniques used were identified and coded at the end of the operation. The frequency with which these different techniques were used is listed in Table 2. Anticoagulation was stopped after 2–3 months unless there was a medical condition that required it continuation.

Follow-up

A 4-week postoperative assessment of each patient was performed in a hospital clinic. Patients were subsequently followed up yearly by means of clinic visits, mailed or electronic questionnaires, and in case of non-respondence, they were contacted by telephone during which the questionnaire was filled by trained personnel; the number of patients contacted by each method was 15%, 555 and 25% respectively. Because response time varied considerably from patient to patient, the cross-sectional method of follow-up was employed with the closing dates as five and ten years; the number of completed follow-ups were 156 and 35 respectively. The total number of follow--ups was expected to be 296 and 215 respectively. Post--operative echocardiography was performed at 6 and 12 months, and then every year or when there was a clinical indication. The mean follow-up was 107.4 ± 13.2 months. Postoperative complications were classified as either valve or procedure related by using recommended criteria.[12] 30-day mortality was defined as death occurring within 30 days after surgery in or out of the hospital.

Statistical analysis

The Cox proportional hazards methods were used to analyse the data on recurrence of MR. For survival and follow-up of events, Kaplan–Meier techniques were used with log-rank testing. For recurrence of MR, a classic Kaplan–Meier technique was used with the first echocardiographic follow-up date demonstrating the recurrence of regurgitation as date of the event. Evaluation of multivariate relationships of potential predictive factors for late death, reoperation and MR >2+ was by multivariable Cox regression analysis. Variables with a univariate *p*-value ≤0.1 or those of known biological significance but failing to meet the critical α level were submitted for consideration to multivariable Cox analysis. A stepwise technique was used to enter the selected variables in the analysis. Statistical analysis of the data was performed with IBM SPSS Statistics version 23.

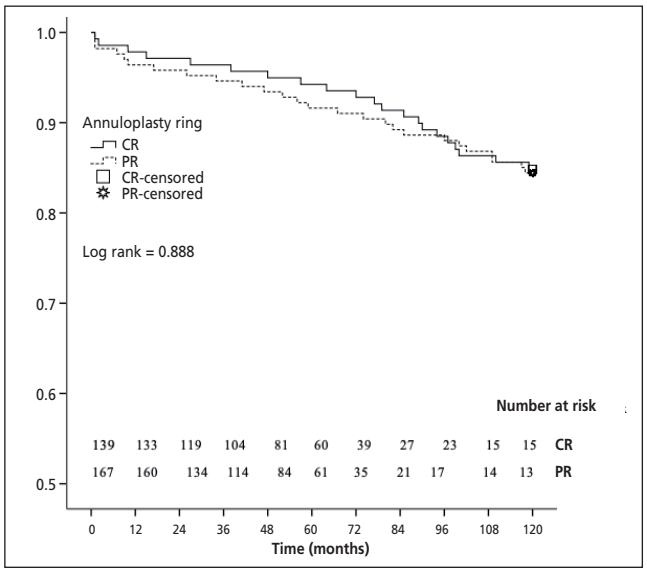

Fig. 1 – 10-year postoperative survival; *p* = 0.177.

Results

Immediate surgical result of mitral valve repair

Operative success was assessed by the echocardiographic examination of MV function within the first postoperative month. At one month postoperatively, 99.0% of all patients had no or trivial mitral regurgitation (CR – 100%, PR – 98.2%). No case of endocarditis was documented.

Survival

Operative mortality was 1.3% out of which one patient died of sepsis with multiple organ failure, two died of complications of acute myocardial infarction and one death was associated with low cardiac output. Survival at five years was 94.1% and 84.6% at ten years (Fig. 1). Survival

Table 3 – Postoperative outcomes

n, (%)	Total	CR	PR	*p*-value
Operative mortality	4 (1.3%)	1 (0.3%)	3 (1.0%)	0.085
Mortality at 5 yrs	18 (5.9%)	7 (2.3%)	11 (3.6%)	0.301
Mortality at 10 yrs	47 (15.4%)	21 (6.9%)	26 (8.5%)	0.177
Recurrent MR >2+ at 5 yrs	39 (12.7%)	17 (5.6)	22 (7.1%)	0.071
Recurrent MR >2+ at 10 yrs	78 (25.5%)	36 (11.8%)	42 (13.7%)	0.110
Reoperation at 5 yrs	12 (3.9%)	7 (3.3%)	5 (1.6%)	0.281
Reoperation at 10 yrs	14 (4.6%)	8 (2.6%)	6 (2.0%)	0.167

CR – classic rigid ring; MR – mitral regurgitation; PR – physio semi-rigid ring.

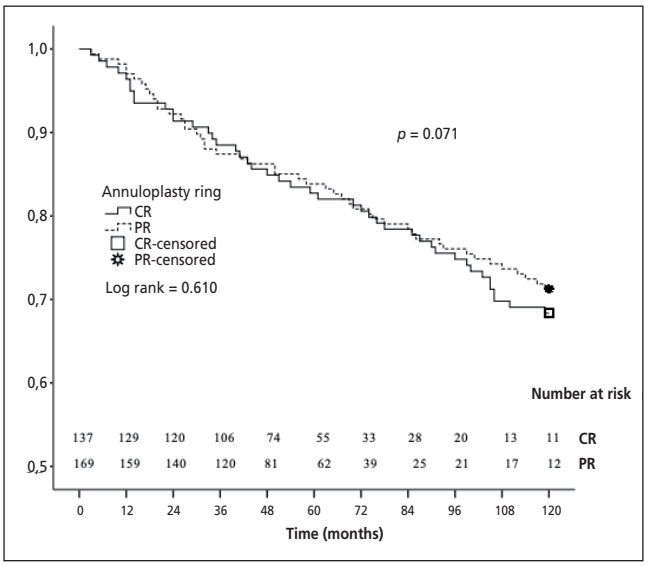

Fig. 2 – 10-year freedom from reoperation and recurrent MR >2+; $p = 0.0715$.

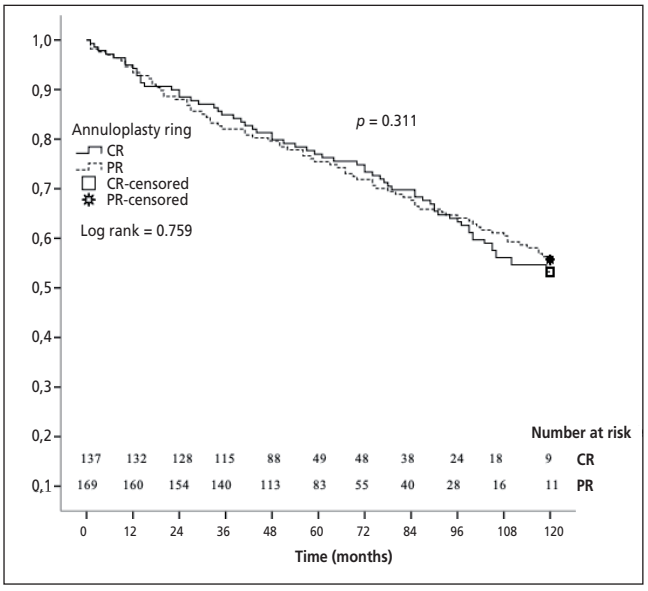

Fig. 3 – Freedom from all major events at ten years; $p = 0.311$.

was identical in the two groups ($p = 0.177$) and in patients with and without concomitant TVR ($p = 0.082$). The causes of deaths were: heart failure (15), cardiac arrhythmias (7), chronic renal failure (5), cancer (3), stroke (4). The cause of nine deaths were unknown. We checked the national death registry to ensure that those censored in the course of follow-up were not dead, and no additional deaths apart from what we recorded were identified (Table 3).

Recurrence of mitral regurgitation

Freedom from reoperation at five years was 96.1% and 95.4% at 10 years (CR – 97.4% and PR – 96.4%; $p = 0.167$). Freedom from recurrent MR > 2+ was 99.0% at one month, 87.3% at five years, and 74.5% at ten0 years. When the interval-censored Turnbull approach is used to calculate the freedom from recurrence of mitral incompetence, similar results are obtained. In all patients, freedom from failing repair was better in FED (87.4%) than in Barlow disease (55.4%) ($p = 0.022$). Ten-year freedom from repair failure (reoperation and recurrent MR > 2+) from all major events (mortality, reoperation, recurrent MR > 2+) were 69.9% and 54.6% respectively (Figs 2 and 3 respectively).

Clinical outcome and morbidity

Patients had an average of six echocardiograhies during follow-up, and NYHA class was recorded at the latest follow-up. 91.3% of the patients improved by at least one NYHA functional class: 72% in class I, 21% in class II, 7% in class III. Eleven patients who had radiofrequency ablation had recurrent of AF and five others underwent a pacemaker implantation. Freedom from thromboembolic events and/or major anticoagulant-related bleeding was 98.0% at five years and 96.1% at ten0 years for all patients.

There were two cases of haemolytic anaemia in the PR group the cause of which was found to be paravalvular regurgitation at the anterolateral commissure and P2 segments of the annulus on post-operative trans-esophageal echocardiogram. Both patients had valve replacements and the anaemia resolved. Two patients had reoperation for early postoperative sternal re-wiring following fracture of the wires and sternal instability.

Predictive factors of recurrent MR >2+

Significant univariate predictors of recurrent MR >2+ and/or reoperation were Barlow's disease, preoperative MR >3+ and use of chordal shortening. By multivariate analysis significant predictors of recurrent MR >2+ and/or reoperation were Barlow's disease, shortening chordoplasty, anterior/bileaflet involvement, leaflet and/or annular calcification. Old age (≥70 years), NYHA functional class IV and high pulmonary artery systolic pressure (≥40 mmHg) were independent predictive factors for poor survival by univariate analysis (Table 4).

Changes in LV function

The results of this study indicated little difference in the influence on postoperative cardiac function between CR and PR. During the first week after surgery, noticeable changes that occurred in the LV were reduction in LVEF or LVEDD. These changes were considered to be related to the sudden elimination of MR, which led to afterload augmentation and volume load reduction. During the next six months and onwards, several gradual changes were noticed, such as recovery of LVEF and further reduction of LVEDD and LVESD. These changes may have been related to the LV remodelling process after correction of MR (Table 5).

Discussion

The MA is a dynamic structure that actively contributes to the mechanics of the MV apparatus, thanks to its sphincter-like action achieved by the contraction and relaxation of baso-constrictor muscles surrounding the annulus posteriorly. An annuloplasty ring is intended to remodel annular deformity secondary to chronic atrial and ventricular enlargement, to stabilize repair by reducing the

Table 4 – Univariate and multivariate Cox analysis

Analysis	Hazard ratio	CL 95%	*p*-value
For reoperation and MR >2+			
Univariate analysis			
Barlow's disease	2.12	1.15–3.03	<0.001
Preoperative MR >3+	2.04	1.00–3.59	0.011
Chordal shortening	1.83	0.97–2.01	0.002
Multivariate analysis			
Barlow's disease	2.78	1.88–3.06	0.021
Chordal shortening	2.00	0.16–2.06	0.003
Anterior or bileaflet involvement,	1.62	0.97–1.98	<0.001
Leaflet and/or annular calcification	1.43	0.10–2.01	0.012
For survival			
Univariate analysis			
NYHA functional class IV	1.59	1.06–2.12	<0.010
Old age (≥ 70 years) and	1.53	0.61–3.00	0.022
Pulmonary artery systolic pressure (≥ 40 mm Hg)	1.78	1.08–2.18	0.002

MR – mitral regurgitation; NYHA – New York Heart Association.

tension on reconstructed valvular portions, to enhance leaflet coaptation by reducing the mitral surface area and to prevent further annular dilatation.

The CR is reported to reduce the dynamic annular motion affecting transvalvular blood flow in the diastole, altering ventricular/valvular interaction and impairing LV function.[9,14,15] Furthermore, CR changes the physiological saddle shape of the MA to a planar configuration.[16] This effect is reported to predispose the development of LVOTO by exacerbating mitral-leaflet SAM, or by narrowing the intersection angle between the aortic and the mitral--valvular planes.[17]

The PR was engineered to avoid the aforementioned drawbacks of the CR.[7,9] Nevertheless, it was subsequently demonstrated that the CR itself was not responsible for these complications[6,7] and that the LV performance actually improved after remodelling.[18] The culprits in the development of LVOTO were later identified to be excess tissue of the posterior leaflet and inadequate ring sizing, resulting in too small a ring for a too large anterior leaflet.[19] It has since been demonstrated that SAM and LVOTO in most cases resolved with volume loading and if necessary, by the use of beta blockers.[19,20]

Whilst CR is made of titanium alloy covered by a layer of silicone rubber and polyester knit fabric, PR is constructed of Elgiloy bands separated by polyester film strips, which provide high-strength fatigue resistance and excellent spring efficiency. The latter comes in a saddle shape to conform to the bulging of the aortic root whereas the former has a kidney shape.

The PR combines remodelling by selective rigidity (a feature of the CR) at the anterior section and selective flexibility (a feature of flexible rings) at the posterior section to give a significant reduction of stress on sutures while maintaining the annulus remodelling effect.[21] It conforms to the configuration of the normal MA during systole, with the characteristic 3 : 4 ratio between the anteroposterior and the transverse diameters. The commissural and posterior sections exhibit a differential flexibility to make possible changes in size and shape of the annulus fibrosus during ventricular contraction.

The PR is reported to maintain normal trans-mitral gradient pressure with excellent mid-term results.[22,23] It has gained much popularity ever since Carpentier et al. reported in 1995 that it reduced LVEDD and LVESD whilst improving LV function.[24] Nonetheless, there is an understanding that its decreased ability to geometrically remodel especially the posterior annulus can have a detrimental effect on late repair durability. Despite its perceived superiority, several studies reported no difference in the general outcome between it, the rigid, and flexible rings.[25,26]

Green et al.[27] reported similar effects of flexible and semi-rigid rings on LV function in an animal randomized study. Manabe et al. in a retrospective, propensity score matched study also demonstrated no significant difference in LV ejection, LVEDD and LVESD between these two rings.[27] Comparable clinical and echocardiographic outcomes were reported by Chung et al. who however documented a greater tendency towards mitral stenosis in the Duran flexible ring. They ascribed this to late pannus formation. On the contrary, Spiegelstein et al. in a retrospective study showed that in degenerative MR, PR was associated with lower rates of recurrent MR than flexible rings.[28] A comparison of pericardial and CR annuloplasty also reported similar clinical and echocardiographic outcomes.[5]

David et al. as well as Okada et al. showed significantly better LV function with flexible rings than with rigid rings[9,15] whilst Bogachev et al. reported that LV changes were more significant in the flexible bands than in rigid rings.[29] In a study by Chang et al., not only were the echocardiographic outcomes similar, they reported comparable clinical outcomes for the two rings at a mean follow-up of 46.6 ± 32.6 months.[30]

UngerGraeber et al.[31] also reported comparable trans--mitral velocity and pressure gradient between the classic rigid ring and Duran flexible ring. Shahin et al.[10] compared the CR and PR in a randomized study and reported similar morbidity, mortality, and LV function at five years of follow-up. Interestingly, mortality was higher in the CR group by 16% and yet was not significant.

Our results confirm available clinical reports of good survival, freedom from recurrent significant MR and free-

Table 5 – Left ventricular changes

	CR			PR		
	Preop.	Postop.	Last f/u	Preop.	Postop.	Last f/u
LVEF (%)*	59.5 ± 7.8	53.5 ± 8.5	58.1 ± 10.0	61.2 ± 9.9	57.3 ± 5.8	60.1 ± 11.0
LVESD (mm)*	47.3 ± 6.7	43.8 ± 8.8	38.5 ± 9.6	46.3 ± 9.9	42.0 ± 4.5	39.3 ± 6.1
LVEDD (mm)*	59.7 ± 10.1	47.7 ± 7.6	47.0 ± 8.2	58.6 ± 9.7	49.9 ± 10.0	49.0 ± 6.6
LAD (mm)	53.1 ± 5.2	45.0 ± 2.6	44.5 ± 6.2	52.6 ± 9.2	44.6 ± 4.4	44.9 ± 7.2

CR – classic rigid ring; last f/u – last follow-up; LAD – left atrial dimension; LVEDD – left ventricular end-diastolic dimension; LVEF – left ventricular ejection fraction; LVESD – left ventricular end-systolic dimension; Postop. – postoperative (immediate); PR – physio semi-rigid ring; Preop. – preoperative. * All parameters were changed significantly ($p< 0.001$) between postoperative and last follow-up at serial examination by means of echocardiography. There were no significant differences between the two rings in each parameter (repeated-measures analysis of variance).

dom from reoperation in repair for degenerative MVD.[32–34] We recorded a low 10-year mortality (15.4%; 6.9% in CR and 8.5% in PR, $p = 0.177$). Our 10-year recurrent MR >2+ was also 25.5% (11.8% in CR and 13.7% in PR, $p = 0.110$) and so was reoperation at just 4.6% (2.0% in CR and 2.6% in PR, $p = 0.167$). We associated the worse clinical outcomes (though not significant) in the PR group with the larger number of patients with Barlow's disease in this group. We also noticed a slightly higher trans-mitral pressure gradient (6.8 ± 1.93 mmHg) in the CR group than in the PR group on early postoperative echocardiography which normalised on the next echocardiography.

This study in accordance with others[35] shows that recurrent MR on echocardiographic studies is more frequent than the reoperation rate indicates implying that reoperation rate is not an optimal predictor of recurrent MR and is not the best parameter to estimate durability of MV repair. A 20-year study of repair for MV prolapse concluded that the therapeutic consequences of recurrent MR may be delayed for several years after onset of recurrent regurgitation.[36]

Our early postoperative echocardiography showed excellent results. All patients in the CR group and 98.2% of those in PR group had no or trivial MR. Nevertheless, recurrent MR occurred at a constant rate during the following years with symptomatic cases being reoperated. Similar to other studies,[37] factors that predicted recurrence of MR or reoperation were Barlow's disease, a preoperative MR >3+ and the use of chordal shortening. In our case however, the number of recurrent MR associated with chordal shortening was not large enough to reach a conclusive assessment. Degenerative process progresses even after repair, so to mitigate recurrence of MR, generous resection of diseased portions of the posterior leaflet is required. Furthermore, chordae with degenerative changes should be managed using artificial chordal implantation and chordal resection with transfer.

Following Flameng et al.[31] report that when recurrent MR be it minor, moderate, or severe, is considered, only about 50% of patients remain free from more than trivial MR at seven years after repair, valve re-repair or replacement on a CPB rerun was routinely performed when residual MR greater than trivial was noticed on intra-operative echocardiography. In cases of significant recurrent MR after hospital discharge, the institution's policy then was valve replacement if the patient agreed to a redo surgery; otherwise, they were recommended medical treatment under the supervision of their physician.

More than 40% of the patients showing significant recurrent MR have a new leaflet prolapse (mainly from the anterior leaflet) which is associated with continuing valve degeneration, retraction of repaired posterior leaflet, or even due to chordal rupture or elongation. Furthermore, half of these valves have leaflet thickening and one third have new calcifications.[13] The MV undergoes these changes irrespective of the type of implanted ring. In the 14 cases of reoperation for repair failure in this study (eight in CR and six in PR), there were nine cases of chordal rupture that were initially shortened, three cases of further anterior leaflet degeneration and two scenarios of annuloplasty suture dehiscence. Valve replacement was performed in all 14 circumstances. Despite the substantial number of cases of Barlow's disease, there was no case of LVOTO most probably because large rings (sizes >34 mm) were used for patients with extensive leaflet enlargement and annular widening. More patients in PR than in CR received larger rings due to higher number of patients with Barlow's disease in this group.

When patients bearing the surgical risk (i.e., use of chordal shortening) are excluded from the analysis, our recurrence rate drops from 2.6% per year to 1.7% per year. This residual rate of 1.7% per year can be attributed to the phenomenon of valve degeneration. Recurrence rate in Barlow's disease is 6.0% per year and 2.6% per year in FED. However, the impact of surgical risk factors (like chordal shortening, inadequate leaflet resection) is so high that after correction for these techniques, the residual recurrence rate decreases to almost that of FED (2.9 vs 2.6% per year).

Limitations

In addition to the general limitations inherent in retrospective series, the choice of classic CR or PR, which was left to the surgeon, may represent a bias in the distribution of baseline characteristics between groups. Preoperative and postoperative data, such as annular size, tenting height, or tenting area, were available only in a small subset of patients, precluding a meaningful conclusion. The postoperative echocardiographic examinations were not performed at a similar interval of time from surgery. However, it is unlikely that this difference had an impact on MV hemodynamic performance. Finally, the results of our study cannot be automatically applied to other annuloplasty devices.

Conclusion

We conclude that the long-term clinical and echocardiographic outcomes of repair for degenerative mitral valve disease with the Classic and Physio rings are comparable. We support the use of artificial chordal implantation instead of chordal shortening for degenerative chordae tendinae. We also reiterate the importance of large size annuloplasty rings for Barlow's disease to minimize the incidence of left ventricular outflow obstruction.

Conflict of interest

The authors declare that they have no conflict of interest.

References

1. Bonow RO, Carabello BA, Chatterjee K, et al. ACC/AHA 2006 guidelines for the management of patients with valvular heart disease. Circulation 2006;114:E84–E231.
2. Barlow JB, Pocock WA. Billowing, floppy, prolapsed or flail mitral valves? Am J Cardiol 1985;55:501–502.
3. Carpentier A, Chauvaud S, Fabiani JN, et al. Reconstructive surgery of mitral valve incompetence: ten-year appraisal. J Thorac Cardiovasc Surg 1980;79:338–348.
4. Sonal C, Ivan SS, Lissa S, et al. Characterisation of degenerative mitral valve disease using morphologic analysis of real-time three-dimensional echocardiographic images. Objective insight into complexity and planning of mitral valve repair. Circ Cardiovasc Imaging 2011;4:24–32.
5. Sidiki AI, Faybushevich AG, Lishchuk AN. A second look at autopericardial mitral annuloplasty. Cor Vasa 2020;62:37–43.
6. Wan S, Lee AP, Jin CN, et al. The choice of mitral annuloplastic ring-beyond "surgeon's preference". Ann Cardiothorac Surg 2015;4:261–265.
7. Kreindel MS, Schiavone WA, Lever JM, Cosgrove D. Systolic anterior motion of the mitral valve after Carpentier ring valvuloplasty for mitral valve prolapse. Am J Cardiol 1986;57:408–412.
8. Carpentier AF, Lessana A, Relland JY, et al. The "Physio-Ring": an advanced concept in mitral valve annuloplasty. Ann Thorac Surg 1995;60:1177–1986.
9. David TE, Komeda M, Pollick C, Burns RJ. Mitral valve annuloplasty: the effect of the type on left ventricular function. Ann Thorac Surg 1989;47:524-8.
10. Shahin GM, van der Heijden GJ, Bots ML, et al. The Carpentier-Edwards Classic and Physio mitral annuloplasty rings: a randomized trial. Heart Surg Forum 2005;8:E389–E394.
11. Fornes P, Heudes D, Fuzellier JF, et al. Correlation between clinical and histologic patterns of degenerative mitral valve insufficiency: a histomorphometric study of 130 excised segments. Cardiovasc Pathol 1999;8:81–92.
12. Akins CW, Miller DC, Turina MI, et al. Guidelines for reporting mortality and morbidity after cardiac valve interventions. J Thorac Cardiovasc Surg 2008;135:732–738.
13. Van Rijk-Zwikker GL, Mast F, Schipperheyn JJ, et al. Comparison of rigid and flexible rings for annuloplasty of the porcine mitral valve. Circulation 1990;82(Suppl IV):58–64.
14. Okada Y, Shomura T, Yamaura Y, Yoshikawa J. Comparison of the Carpentier and Duran prosthetic rings used in mitral valve reconstruction. Ann Thorac Surg 1995;59:658–663.
15. Dall'Agata A, Taams MA, Fioretti PM, et al. Cosgrove–Edwards mitral ring dynamics measured with transesophageal three-dimensional echocardiography. Ann Thorac Surg 1998;65:485–490.
16. Schiavone WA, Cosgrove DM, Lever HM, et al. Long-term follow-up of patients with left ventricular outflow tract obstruction after Carpentier ring mitral annuloplasty. Circulation 1988;78(Suppl I):60–65.
17. Bonchek LI, Olinger GN, Siegel R, et al. Left ventricular performance after mitral reconstruction for mitral regurgitation. J Thorac Cardiovasc Surg 1984;88:122–127.
18. Mihaileanu S, Marino JP, Chauvaud S, et al. Left ventricular outflow obstruction after mitral valve repair (Carpentier's technique). Proposed mechanisms of disease. Circulation 1988;78(Suppl 1):78–84.
19. Carpentier A. The SAM issue. Le Club Mitrale Newsletter 1989;1:5.
20. Carpentier AF, Lessana A, Relland JY, et al. The "physio-ring": an advanced concept in mitral valve annuloplasty. Ann Thorac Surg 1995;60:1177–1185. Discussion 1185–1186.
21. Raffoul R, Uva MS, Rescigno G, et al. Clinical evaluation of the Physio annuloplasty ring. Chest 1998;113:1296–1301.
22. Accola KD, Scott ML, Thompson PA, et al. Midterm outcomes using the physio ring in mitral valve reconstruction: experience in 492 patients. Ann Thorac Surg 2005;79:1276–1283. Discussion 1276–1283.
23. Chan DT, Chiu CS, Cheng LC, Au TW. Mitral Valve Annuloplasty With Carpentier–Edwards Physio Ring: Mid-term Results. Asian Cardiovasc Thorac Ann 2006;14:382–386.
24. Chee T, Haston R, Togo A, Raja SG. Is a flexible mitral annuloplasty ring superior to a semi-rigid or rigid ring in terms of improvement in symptoms and survival? Interact Cardiovasc Thorac Surg 2008;7:477–484.
25. Khamooshian A, Buijsrogge MP, de Heer F, Gründeman PF. Mitral valve annuloplasty rings: review of literature and comparison of functional outcome and ventricular dimensions. Innovations (Phila) 2014;9:399–415.
26. Green GR, Dagum P, Glasson JR, et al. Semirigid or flexible mitral annuloplasty rings do not affect global or basal regional left ventricular systolic function. Circulation 1998;98:II128–II135. Discussion II135–II136.
27. Spiegelstein D, Moshkovitz Y, Sternik L, et al. Midterm results of mitral valve repair: closed versus open annuloplasty ring. Ann Thorac Surg 2010;90:489–496.
28. Bogachev-Prokophiev AV, Afanasyev AV, Zheleznev SI, et al. Mid-term results of mitral valve repair using flexible bands versus complete rings in patients with degenerative mitral valve disease: a prospective, randomized study. J Cardiothorac Surg 2017;12:113.
29. Chung CH, Kim JB, Choo SJ, et al. Long-term outcomes after mitral ring annuloplasty for degenerative mitral regurgitation: Duran ring versus CarpentierEdwards ring. J Heart Valve Dis 2007;16:536–544.
30. Unger-Graeber B, Lee RT, Sutton MS, et al. Doppler echocardiographic comparison of the Carpentier and Duran anuloplasty rings versus no ring after mitral valve repair for mitral regurgitation. Am J Cardiol 1991;67:517–519.
31. Enriquez-Sarano M, Schaff HV, Orszulak TA, et al. Valve repair improves the outcome of surgery for mitral regurgitation: a multivariate analysis. Circulation 1995;91:1022–1028.
32. David TE, Ivanov J, Armstrong S, et al. A comparison of outcomes of mitral valve repair for degenerative disease with posterior, anterior, and bileaflet prolapse. J Thorac Cardiovasc Surg 2005;130:1242–1249.
33. Vergnat M, Jassar AS, Jackson BM, et al. Ischemic mitral regurgitation: a quantitative three-dimensional echocardiographic analysis. Ann Thorac Surg 2011;91:157–164.
34. Flameng W, Herijgers P, Bogaerts K. Recurrence of mitral valve regurgitation after mitral valve repair in degenerative valve disease. Circulation 2003;107:1609–1613.
35. Mohty D, Orszulak TA, Schaff HV, et al. Surgery for valvular heart disease: very long-term survival and durability of mitral valve repair for mitral valve prolapse. Circulation 2001;104(Suppl. I):I1–I7.
36. David TE, Omran A, Armstrong S, et al. Long-term results of mitral valve repair for myxomatous disease with and without chordal replacement with expanded polytetrafluoroethylene sutures. J Thorac Cardiovasc Surg 1998;115:1279–1286.
37. Adams DH, Anyanwu AC, Rahmanian PB, et al. Large annuloplasty rings facilitate mitral valve repair in Barlow's disease. Ann Thorac Surg 2006;82:2096–2101.