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FULL LENGTH ARTICLE

The Carpentier-Edwards Classic and Physio Annuloplasty Rings in Repair of Degenerative Mitral Valve Disease: A Retrospective Study

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Abstract

Background: **Physio ring (SR) is considered an improved version of the Classic rigid ring (RR). Today, SR is more widely used in mitral valve (MV) repair. We sought to compare the long-term outcomes of repair with RR and SR in degenerative mitral valve disease.**

Methods: **In a computerized registry of our institution, 306 patients had MV repair with either RR (139 patients) or SR (167 patients) ring between 2005 and 2015. Fifteen of them had concomitant tricuspid valve repair. Ninety-two (30.1%) had Barlow's disease and 214 (69.9%) had fibroelastic deficiency. The patients 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 not between groups. Survival at 10 years was 84.6% (93.1% in RR and 91.5% in SR; p = 0.177) and 10-year freedom from recurrent MR ≥ 2+ was 74.5% (88.2% in RR and 86.3% in SR; p = 0.110). Reoperations for repair failure were 8 in RR and 6 in SR. By Cox regression analysis, Barlow's disease and preoperative MR = 4+ 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.**

Conclusion: **Long-term outcomes of repair for degenerative MV disease with the Classic and Physio rings are comparable. We also reiterate the importance of large size annuloplasty rings for Barlow's disease to avoid the incidence left ventricular outflow obstruction.**

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

1. Introduction

Mitral valve (MV) repair consists of valvuloplasty and annuloplasty with a rigid, semi-rigid or flexible ring. Annuloplasty rings reduce the mitral annulus (MA) size, prevent its further dilation and restoring proper leaflet coaptation [1]. The range of available annuloplasty 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 1 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. For degenerative mitral valve disease (MVD), a balance needs to be struck between rigidity of design which aids in remodelling and flexibility which preserves the

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dynamic function of the MA [2]. In addition, the incidence of detrimental systolic anterior motion (SAM), adverse trans-mitral pressure gradient and the impact on left ventricular (LV) function must all be considered when choosing an annuloplasty device [3].

Criticisms of the Carpentier-Edwards Classic rigid ring (RR) of causing SAM, left ventricular outflow tract obstruction (LVOTO) and impairment of LV function led to the development of the semi-rigid Physio ring (SR) [2],[4]. Whilst there are so many studies that compared the short and long-term outcomes of different annuloplasty rings, to the best our knowledge, only one randomized study compared the RR and SR [5]. This study aimed to compare the long-term outcomes of MV repair for degenerative MVD with a RR and SR.

Abbreviations

FED	Fibroelastic deficiency
LV	Left ventricle
LVOTO	Left ventricular outflow tract obstruction
MA	Mitral annulus
MR	Mitral regurgitation
MV	Mitral valve
MVD	Mitral valve disease
RR	Carpentier-Edwards Classic rigid ring
SAM	systolic anterior motion of anterior leaflet
SR	Carpentier-Edwards Physio semi-rigid ring
TS	Turbulence slope
VLF	Very-low-frequency
TVR	Tricuspid valve replacement

2. Methods

2.1. Study design

This is a retrospective, nonrandomized review of all patients who underwent valve reconstruction with either the annuloplasty RR or SR 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.

2.2. Patients

A computerized registry of patients at our hospital was used to identify patients who underwent repair for degenerative MVD with/without tricuspid valve repair (TVR) between 2005 and 2015. Three hundred and six consecutive patients had repair with either RR (139) or SR (167). The degenerative MV was identified as either FED or Barlow's disease intraoperatively using the Carpentier guidelines [6]. Preoperative data collected included patient's age, sex, preoperative NYHA functional class, ejection fraction and degree of mitral regurgitation (MR), presence of preoperative atrial fibrillation, diabetes mellitus, and the form of degenerative MVD Table 1.

2.3. Surgical techniques

Patients received MV repair (with concomitant TVR in 15 cases) performed by 4 surgeons. Intraoperative echocardiography was performed in all patients before and after repair. Majority of patients had median sternotomy. Moderate hypothermic (28 ± 30C) 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.

Posterior leaflet prolapse was managed with quadrangular resection, and in cases of extensive tissue overgrowth such as in Barlow's disease, a generous resection was combined with sliding leaflet plasty.; while regurgitation in the absence of leaflet prolapse such as in FED was treated with sliding plasty. Correction of anterior leaflet prolapse was by either chordal transfer or artificial chordal implantation, and chordae that were elongated were either buried within the papillary muscle or the papillary muscle was repositioned to alleviate the prolapse.

Inter-trigonal distance and anterior leaflet height were measured for ring size selection. The choice of ring (RR or SR) was at the discretion of the operating surgeon. Valve competency after repair was evaluated by the saline test, and then by trans-esophageal echocardiography 9 after atrial closure. When residual MR was more than trivial, a re-repair was done on a second pump run. Meanwhile, concomitant radio-frequency ablation was performed for all patients with permanent or paroxysmal AF present for at least 6 months before surgery. All other minor procedures on the valvular apparatus which were performed during the repair process are presented in Table 2. Anticoagulation was up to the fourth month if there was no indication for continuation.

Table 1. Demographic data and mitral valve characteristics.

Characteristics	Total	RR	SR
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%)
Grade 3	147 (48.0%)	82 (59%)	65 (38.5%)
Grade 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%)

RR, classic rigid ring; *SR*, physio semi-rigid ring; *MR*, mitral regurgitation; *NYHA*, New York Heart Association; *PA*, pulmonary artery; *MVD*, mitral valve disease; *FED*, fibroelastic deficiency.

Table 2. Operative data.

Characteristics	Total	RR	SR	*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	–

2.4. 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 5 and 10 years; the number of completed follow-ups were 156 and 35 respectively. The total number of follow-ups were 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 [7]. **30-day mortality** was defined as death occurring within 30 days after surgery in or out of the hospital.

2.5. 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.

Table 3. Postoperative outcomes.

n, (%)	Total	RR	SR	*p* value
30-day mortality	4 (1.3%)	1 (0.3%)	3 (1.0%)	0.085
Mortality at 5yrs	18 (5.9%)	7 (2.3%)	11 (3.6%)	0.301
Mortality at 10yrs	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

RR, classic rigid ring; *SR*, physio semi-rigid ring; *CPB*, cardiopulmonary bypass; *TVR*, tricuspid valve repair; *PTFE*, polytetrafluoroethylene.

3. Results

3.1. Immediate surgical result of mitral valve repair

Operative success was assessed by the echocardiographic examination of MV function within the first postoperative month postoperatively. At 1

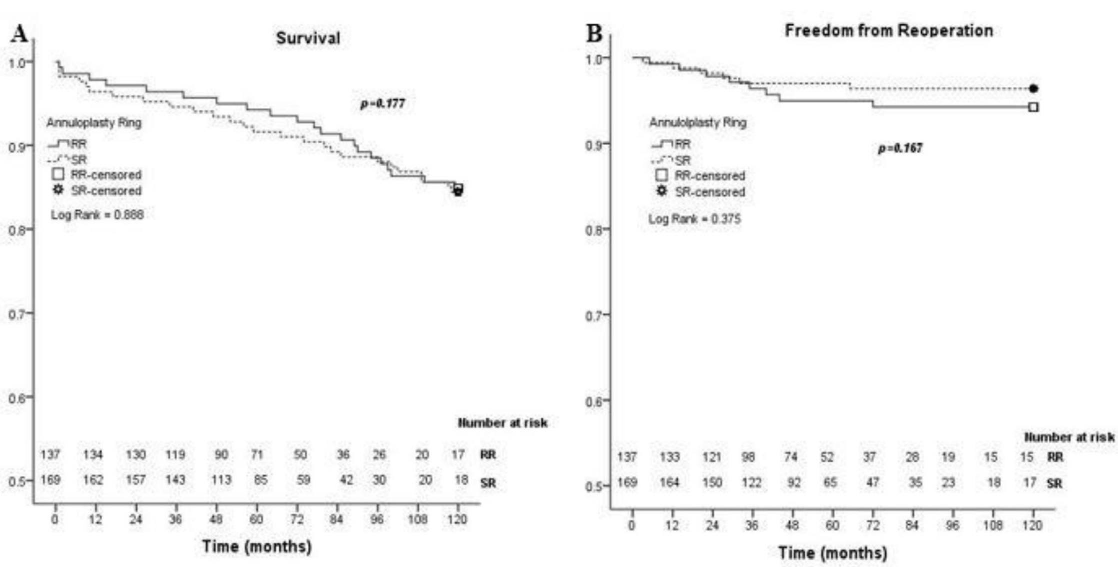

Fig. 1. A- Cumulative survival at 10 years (p = 0.177); B- 10-year freedom from reoperation (p = 0.167).

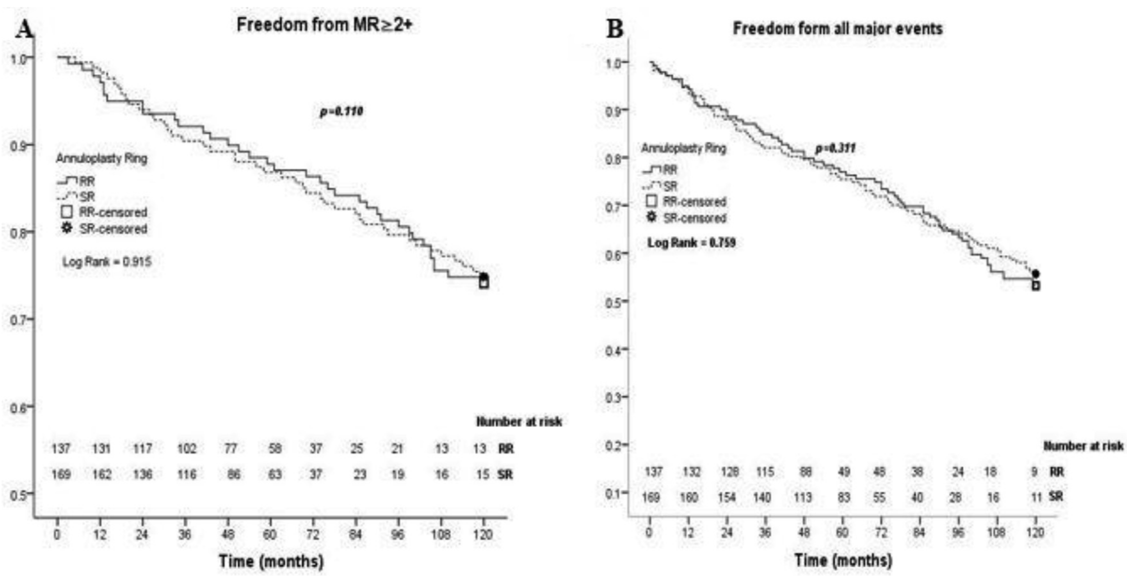

Fig. 2. A- 10-year freedom from recurrent MR $\geq$ 2+ ($p = 0.110$); B- Postoperative freedom from all major events such as death, reoperation or recurrent MR $\geq$ 2+ ($p = 0.311$).

month postoperatively, 99.0% of all patients had no or trivial mitral regurgitation (RR-100%, SR-98.2%). No case of endocarditis was documented.

3.2. Survival

30-day mortality was 1.3% out of which 1 patient died of sepsis with multiple organ failure, 2 died of complications of acute myocardial infarction and 1 death was associated with low cardiac output. Survival at 5 years was 94.1% and 84.6% at 10 years (Fig. 1A). It was identical in the 2 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 causes of 9 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.

3.3. Reoperation rate and recurrence of mitral regurgitation

Freedom from reoperation at 5 years was 96.1% and 95.4% at 10 years (RR -97.4% and SR -98.0%; $p = 0.167$). (Fig. 1B). Freedom from recurrent MR $\geq$ 2+ was 99.0% at 1 month, 87.3% at 5 years,

Table 4. Univariate and Multivariate Cox analysis.

FOR REOPERATION AND MR ≥ 2+			
Analysis	Hazard Ratio	CL 95%	*P* value
<u>Univariate analysis</u>			
Barlow's disease	2.12	1.15–3.03	<0.001
Preoperative MR = 4+	2.04	1.00–3.59	0.011
Chordal shortening	1.83	0.97–2.01	0.002
<u>Multivariate analysis</u>			
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			
<u>Univariate analysis</u>			
NYHA functional class IV,	1.59	1.06–2.12	<0.010
Old age (≥70 years) and Pulmonary artery systolic pressure (≥40 mm Hg)	1.53	0.61–3.00	0.022
Pulmonary artery systolic pressure (≥40 mm Hg)	1.78	1.08–2.18	0.002

RR, classic rigid ring; *SR*, physio semi-rigid ring; *MR*, mitral regurgitation.

Table 5. Left ventricular changes.

	RR			SR		
	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

MR, mitral regurgitation; NYHA, New York Heart Association, *RR*, classic rigid ring; *SR*, physio semi-rigid ring; *Preop*, Preoperative; *Postop*, postoperative (immediate); *Last f/u*, last follow-up; *LVEF*, left ventricular ejection fraction; *LVESD*, left ventricular end-systolic dimension; *LVEDD*, left ventricular end-diastolic dimension; *LAD*, left atrial dimension. *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 2 rings in each parameter (repeated-measures analysis of variance).

and 74.5% at 10 years (Fig. 2A). 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 $\geq$ 2+) and from all major events (mortality, reoperation, recurrent MR $\geq$ 2+) were 69.9% and 54.6% respectively. (Fig. 2B).

3.4. Clinical outcome and morbidity

Patients had an average of 6 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 patient who had radiofrequency ablation had recurrent of AF and 5 others received a pacemaker implantation. Freedom from thromboembolic events and/or major anticoagulant-related bleeding was 98.0% at 5 years and 96.1% at 10 years for all patients.

There were 2 cases of haemolytic anaemia in the SR 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.

3.5. Predictive factors of recurrent MR $\geq$ 2+

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

3.6. Changes in LV function

The results of this study indicated little difference in the influence on postoperative cardiac function between RR and SR. 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 6 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.

4. Discussion

The RR is intended to remodel MA deformity, stabilize repair by reducing the tension on reconstructed valvular portions, to enhance leaflet coaptation by reducing the mitral surface area and to prevent further annular dilatation. However, it reported to reduce the dynamic annular motion affecting transvalvular blood flow in the diastole, altering ventricular/valvular interaction and impairing LV function [4],[8],[9]. It also changes the physiological saddle shape of the MA to a planar configuration. reportedly causing LVOTO by exacerbating mitral-leaflet SAM, or by narro wing the intersection angle between the aortic and the mitral–valvular planes [10].

The aforementioned drawbacks of the RR pave the way for the construction of the SR eventhough it was subsequently demonstrated that RR itself was not responsible for these complications and that the LV performance actually improved after remodelling [2],[11],[12]. Excess posterior-leaflet tissue and inadequate ring sizing (resulting in too small a ring for a too large anterior-leaflet) were identified as the culprits of LVOTO which nonetheless resolves in most cases with volume loading or by the use of beta blockers [13],[14].

Whilst the RR is made of titanium alloy covered by a layer of silicone rubber and polyester knit fabric, the Physio SR 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 SR combines remodelling by selective rigidity (a feature of the RR) 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 [15]. It conforms to the configuration of the normal MA during systole, with the characteristic 3:4 ratio between the anteroposterior and the transverse diameters. It is also reported to maintain normal trans-mitral gradient pressure with excellent mid-term results [16],[17]. After Carpentier et al. report in 1995 that the SR reduces LV end systolic and end diastolic diameters whilst improving LV function, it gained popularity among MV surgeons [18]. Nevertheless, 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 rigid, semi-rigid and flexible annuloplasty rings [19].

Green et al. [20] 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 LVEF, LVEDD and LVESD between these two rings [21]. A comparison of pericardial and SR annuloplasty also reported similar clinical and echocardiographic outcomes.[1]

David et al. including many others reported comparable clinical and echocardioraphical outcomes in flexible and rigid rings [4],[9],[22] Shahin et al. in a randomized study reported similar morbidity, mortality and LV function in the RR and SR at 5 years of follow-up [5].

Our results confirm available clinical reports of good survival, freedom from recurrent significant MR and freedom from reoperation in repair for degenerative MVD [23–25]. We recorded a low 10-year mortality (15.4%; 6.9% in RR and 8.5% in SR, $p = 0.177$). Our 10-year recurrent MR $\geq 2+$ was also 25.5% (11.8% in RR and 13.7% in SR, $p = 0.110$) and so was reoperation at just 4.6% (2.6% in RR and 2.0% in SR, p = 0.167). We associated the worse clinical outcomes (though not significant) in the SR 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 RR group than the SR group on early postoperative echocardiography which normalised on the next echocardiography.

This study in accordance with other studies indicates that recurrent MR on echocardiographic studies is more frequent than the reoperation rate indicates implying that reoperation rate is not the best parameter to estimate durability of MV repair [26]. 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 [27].

At early postoperative echocardiography all patients in the RR group and 98.2% of those in SR group had no or trivial MR. Nevertheless, recurrent MR occurred at a constant rate during the following years. **Similar to other studies, factors that predicted recurrent MR or reoperation were Barlow's disease, a preoperative MR = 4 + and the use of chordal shortening** [28]. **In our case however, the number of recurrent MR associated with chordal shortening was not large enough to reach a conclusive assessment.** Because degenerative process progresses even after repair, to mitigate recurrence of MR, generous resection of diseased portions of the posterior leaflet is required. Furthermore, chordae with degenerative changes should be managed by artificial chordal implantation or resection with transfer.

Following Flameng and co-workers 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 7 years after repair [29], 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 of elongation [6]. The MV undergoes these changes irrespective of the type of ring implanted.

In the 14 cases of reoperation for repair failure in this study, there were 9 cases of rupture of initially shortened chordae, 3 cases of progressive anterior leaflet degeneration and 2 instances of annuloplasty suture dehiscence. Despite the substantial number of cases of Barlow's disease, we did not find any 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 SR than in RR received larger rings due to higher number of cases of Barlow's disease.

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).

5. Limitations

In addition to the general limitations inherent in retrospective series, the choice of classic RR or physio SR, 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.

6. Conclusion

We conclude that the long-term clinical and echocardiographic outcomes of repair for degenerative MVD with the Classic and Physio rings are comparable. We also reiterate the importance of large size annuloplasty rings for Barlow's disease to avoid the incidence left ventricular outflow obstruction.

Ethics approval and consent to participate

The study was approved by the internal Institutional Review Board with a waiver for patient consent.

Funding

Not applicable.

Consent for publication

Not applicable.

Availability of data and materials

The datasets during and/or analysed during the current study are available from the corresponding author on reasonable request.

Conflicts of interest

The authors declare that they have no competing interests.

Author contribution statement

Abubakari I. Sidiki: Design, Data collection and/or processing, Analysis and/or interpretation, Literature review, Writer; **Alexandr G. Faybushevich**: Supervision, Data collection and/or processing, Analysis and/or interpretation, Literature review, Writer; **Alexandr N. Lishchuk**: Conception, Design, Supervision, Analysis and/or interpretation, Writer, Critical review; **Alexandr N. Koltunov**: Conception, Design, Data collection and/or processing, Analysis and/or interpretation, Writer, Critical review; **Ekaterina A.Roshchina**: Data collection and/or processing, Literature review, Critical review.

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